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REVIEW OF THE POTENTIAL MECHANISATION OF KELP HARVESTING IN IRELAND

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EXECUTIVE SUMMARY

In recent decades a diverse seaweed industry has developed in Ireland. Currently, the most economically important seaweeds are the brown alga *Ascophyllum nodosum* and two species of red calcified coralline algae, referred to as maerl. In Ireland, natural sustainable seaweed resources are under-utilised and the industrial potential including high-value applications has not been fully realised (National Seaweed Forum, 2000). The introduction of mechanical harvesting of seaweed was identified as a key area in the development of the domestic seaweed industry and is currently being considered due to an increased demand for seaweed. The objective of this study is to provide an overview of kelp research, harvesting techniques and resource management in other European countries.

Kelp species are the largest and structurally most complex brown algae. They are found in the lower intertidal and subtidal of Atlantic and Pacific rocky shores of the Northern and Southern Hemisphere and often form dense standing stocks, known as kelp forests. They are exploited world-wide and are of major economic importance to the hydrocolloid industry as a source for alginates.

Kelp forests are of high ecological significance. They are complex three-dimensional structures providing habitat, food and shelter for various species and are characterised by high productivity and a high diversity of associated flora and fauna. They also form important reproduction and nursery grounds for fish.

In Europe two kelp species, *Laminaria digitata* and *L. hyperborea*, are commercially exploited by the hydrocolloid industry. They are also utilised by the cosmetic and agrochemical industries and for biotechnological applications. Because kelp species are long-lived and are of major importance as constituents of the benthic lower intertidal and subtidal ecosystems, specific management schemes have been developed to ensure sustainable harvesting.

In France, about 60,000 tonnes of *L. digitata* are harvested annually, primarily in Brittany, for the French hydrocolloid industry. Specialised mechanical harvesting equipment called "scoubidou" is used. Seaweed harvesting is regulated by the French Government and the National Syndicate of Marine Algae, which is a group drawn from the kelp industry (comprised of two companies), fishermen and scientific advisers. Sixty boats are licensed for harvesting of *L. digitata*. Landings of raw material per boat are restricted to 1,000 - 1,500 tonnes *per annum*. On average, 30% of the biomass of a kelp forest is harvested. Regulations of harvesting times are imposed to make allowance for growth, reproduction and regeneration of kelp beds. These measures are thought to be sufficient to ensure sustainable harvesting. *L. digitata* is a relatively fast growing alga with a life span of 3 - 5 years. Thus, because of the short regeneration time, there are no official regulations on fallow periods. Only in certain areas supporting only a small number of fishing boats, fishermen have introduced fallow periods in self-management. The environmental impact of kelp harvesting is monitored frequently. In general, kelp beds show a relatively fast regeneration. In recent years, however, a decline of *L. digitata* beds and an increase in the occurrence of *Saccorhiza polyschides* have been observed. This annual, fast growing, opportunistic kelp species is of no commercial interest. The over-harvesting and/or an increase in water temperature, due to climate change, could be leading to

the increased abundance of *S. polyschides* and the consequential replacement of *L. digitata* and the exhaustion of *L. hyperborea* fields.

In Norway, about 160,000 tonnes of *L. hyperborea* are harvested annually by an industry comprising of one company. Special seaweed dredges are used for harvesting. The Directorate of Fisheries, State Agencies, Research Institutions, fishermen and the industry implement the management schemes. A central aspect of this is the allocation of harvesting areas, subdivided in smaller fields, which are allowed to be harvested every 6 years in a defined order. This results in the removal of 10 - 15% of total standing stock *per annum*. Harvesting is accompanied by monitoring of kelp beds. Kelp forest ecology and the impact of seaweed dredging has been the subject of extensive research programmes. In general harvesting is performed in a sustainable manner, resulting in no obvious long-term damage of the ecosystem. The destructive grazing of sea urchins and the resultant creation of barren grounds, which can persist over several years is a threat to kelp populations in some parts of the Norwegian coast.

In Ireland, the number of investigations into kelp species and their ecosystem is limited. Recently conducted studies by the Irish Seaweed Centre have provided information on kelp growth, biomass, biodiversity of kelp beds and the impact of experimental harvesting. Based on these data, total natural kelp resources (*L. digitata* plus *L. hyperborea*) are estimated to be 81,641 tons for Galway Bay and about 3,000,000 tonnes for the entire coastline of Ireland.

Prior to the introduction of mechanical seaweed harvesting in Ireland, an appropriate management strategy needs to be developed and put in place to ensure sustainable exploitation of natural resources, while supporting the future development of a viable seaweed industry. Management of the resource should be based on sound scientific knowledge and pursue a precautionary approach. Experience gained in other countries should be taken into account. Initial steps in the process of developing a management strategy should include harvesting trials to assess mechanisms most suitable for Irish conditions, accompanied by studies on the potential environmental impacts. Surveys should also be conducted to provide detailed estimates on standing stock of *L. digitata* and *L. hyperborea*, as well as the location and size of kelp beds suitable for harvesting. Additionally, the economic viability of kelp harvesting should be evaluated. The following aspects should be considered for development of management programmes for kelp resource to ensure sustainability:

- Determination of suitable harvesting methodology (harvesting technology and organisation of harvesting)
- Research and monitoring programmes
- Adequate legislation for mechanical seaweed harvesting including, *inter alia* allocation of kelp harvesting areas
- Regulations on harvestable biomass, harvesting times and fallow periods
- Control mechanisms to ensure sustainable harvesting and compliance with official regulations and
- Interactions with other users

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INTRODUCTION

A diverse seaweed industry has developed in Ireland over the past few decades. The seaweed industry today comprises several sectors, such as biopolymers, agriculture/horticulture, cosmetics, thalassotherapy and human consumption, with the former two sectors being of most economic importance. Approximately sixteen seaweed species are commercially utilised, three of which are of particular commercial importance. These are the calcified red algae, referred to as maërl, which mainly comprises of two species (*Phymatolithon calcareum* and *Lithothamnion corallioides*) and are exploited by a single company for agricultural, horticultural, food and cosmetic applications. The other bulk species is the brown alga *Ascophyllum nodosum*, which is used for alginate extraction and agriculture/horticulture applications. The latter species sustains an industry, which is an important factor in contributing to the maintenance of coastal communities especially in rural areas of the west coast, particularly in the Gaeltacht of Connemara (Guiry 1997, National Seaweed Forum, 2000).

Mechanical harvesting of seaweeds in Ireland is limited to the exploitation of maërl. At present, one company has a licence to harvest calcified algae in the south-west of Ireland (Bantry Bay) with 8,000 - 10,000 wet tonnes of maërl being extracted from the seabed annually in recent years. The supply of raw material for the *Ascophyllum*-processing industry as well as for the other industrial sectors relies on harvesters who harvest the seaweed by hand. Although hand-harvesting provides a source of employment in rural areas along the west coast, the age profile is increasing and the numbers of harvesters are declining due to insufficient recruitment of younger harvesters (National Seaweed Forum 2000; Kelly *et al.* 2001). With growing demands for seaweeds, it is uncertain whether hand-harvesting will provide sufficient raw material in the long-term.

The National Seaweed Forum has evaluated the current state of the Irish Seaweed Industry. The forum was launched by the Minister for Marine and Natural Resources in 1999 and consists of 19 members from state agencies, third-level institutions and industry. In the final report (National Seaweed Forum, 2000) it was stated that the natural sustainable seaweed resources in Ireland are under-utilised and the industrial potential, including high-value applications, has not been fully realised. The National Seaweed Forum identified two key areas as being crucial to the development of the Irish seaweed industry:

- 1) Seaweed aquaculture was assumed to provide the most cost-effective method to meet growing market demand with high-quality seaweed for specific sectors such as human consumption, cosmetics and biotechnology. Additionally, a seaweed aquaculture industry is expected to create attractive and high-skilled jobs, especially in peripheral communities in coastal areas. This is based on the fact that seaweeds of interest to high quality applications are often not bulk species, which are easy to harvest in large amounts. Therefore, with cultivation you strongly increase volume/area, which facilitates harvesting and also standardises quality. Cultivation of a bulk species such as kelp is economically not feasible in Europe.
- 2) The development and introduction of harvesting machinery suitable for Irish conditions was thought to have a significant impact on the expansion of a viable Irish seaweed industry. As a measure to ensure long-term continuity of raw-material supply

of bulk species (e.g. *A. nodosum*, *Laminaria* species) the investigation of mechanical harvesting techniques with emphasis on sustainability and environmental impact were prioritised as an R&D area (National Seaweed Forum, 2000).

An initial comprehensive study of hand and mechanical harvesting of *Ascophyllum nodosum*, including an environmental impact assessment, was conducted in the late 1990s (Kelly *et al.*, 2001). In this study, a device similar to the Norwegian *Ascophyllum* cutter (a flat-bottomed boat fitted with a Vaughan vertical wet-well chopper pump) was used. When hand and mechanical harvesting were compared, there was no significant difference in environmental impact caused by the two methods, but mechanical harvesting was found to be less effective and more expensive than hand harvesting.

At present, kelp species in Ireland such as *L. digitata*, *L. saccharina* and *Alaria esculenta*, are harvested by hand but only in small amounts. This means that the natural sustainable resources of kelps of Irish shores are under-utilised. Due to the economic importance of *L. digitata* and *L. hyperborea* for alginate extraction and the growing demand for kelp by the phycocolloid and other industries, the introduction of mechanical harvesting is currently being considered for Ireland. Mechanised harvesting enables the harvester to remove large amounts of biomass from an area in a relatively short time. It is therefore essential to develop a suitable management scheme to ensure sustainable exploitation of natural resources and continuous integrity of marine habitats.

The objective of the present study is to provide an extensive literature review on kelp research, harvesting and resource management as essential background knowledge for the development of an appropriate management strategy for Ireland. The report addresses the following topics:

- Biology of kelps
- Biodiversity of kelp forests and ecological significance of kelps
- Commercial kelp harvesting in France and Norway (methods, management and environmental impact)
- Investigations of kelp in Ireland (Growth rates, biomass, biodiversity of kelp beds, regeneration potential, kelp resources)
- Legal framework for seaweed harvesting in Ireland
- Conclusions and recommendations

BIOLOGY OF KELPS

2.1 General characteristics

Kelp species represent the largest and structurally most complex brown algae. They comprise different genera, currently all referred to as the order Laminariales. Kelps are the most prominent constituents of the lower intertidal and subtidal of Atlantic and Pacific rocky shores of temperate regions of both the Northern and Southern Hemispheres. As canopy algae they often form dense beds, referred to as kelp forests, supporting a rich understorey of flora and fauna. Worldwide, kelp forests sustain various fisheries and are the source for raw material of the alginate industry. Major factors in determining the bio-geographical distribution of kelp species are the winter and summer seawater isotherms, which set the limits for survival and reproduction.

Five kelp species are indigenous to Ireland: *Saccorhiza polyschides* (Lightfoot) Batters (Fig. 2.1); *Alaria esculenta* (L.) Greville (Fig. 2.2); *Laminaria hyperborea* (Gunnerus) Foslie (Fig. 2.3); *Laminaria digitata* (Hudson) J.V. Lamouroux (Fig. 2.4); and *Laminaria saccharina* J.V. Lamouroux (Fig. 2.5). They differ in various aspects, such as morphology, ecophysiology and longevity, and show distinct patterns of vertical distribution on the shore (see Fig. 2.6). *L. digitata* and *L. hyperborea* are the only species that form extended monospecific kelp beds.

The vertical distribution of these five species on the shore depends on factors such as light penetration, tolerance to desiccation, interspecific competitiveness and adaptation to wave exposure. Kelps inhabit the continuously submersed sublittoral and lower intertidal zones occasionally emerging at extreme low water. Light levels naturally determine the lower limit for algal growth in the sublittoral (Lüning 1990, see Fig. 2.6). In coastal waters rich in particles, the depth limit for kelp growth is about 10 - 15 metres below mean low water, whereas in clearer waters of the open Atlantic coast kelps are found in depths down to 30 - 40 metres.

Along the Irish coast as well as on other north-west European rocky coasts a distinct zonation can be found. In the upper sublittoral, *L. digitata* forms extended uniform kelp beds. With its flexible stipe and deeply divided blade *L. digitata* is well adapted to fast, turbulent water flow and multidirectional mechanical stress. When occasionally exposed at extreme low tide, the algae lie flat on the seabed with the uppermost blades covering the lower ones and thereby protecting them against desiccation (Lüning, 1990).

The extension of *L. digitata* beds into greater depths of the mid-sublittoral zone is restricted by the occurrence of *L. hyperborea*. *Laminaria hyperborea* is less well adapted to strong wave impact of the upper sublittoral zone, but a rigid upright stipe (1-2m in length) ensures maximum exposure of the large digitate blades to light, while shading all other understorey algae. Dense *L. hyperborea* forests are formed down to depths, which obtain 5% of surface light (e.g. a depth of 30 m in Norway). An additional advantage of *L. hyperborea* with respect to its competitiveness is its longevity. Individuals may reach 15 years, whereas other Laminarian species of the upper sublittoral zone generally live no longer than 3 - 4 years (Lüning, 1990).



Photo: www.qualite-info.fr

Fig. 2.1

Species: *Saccorhiza polyschides*

Family: Phyllariaceae

Characteristics: Broad and flat stipe, tough, digitate (divided) blade, bulb-like holdfast, maximal plant height 3 metres. *Saccorhiza polyschides* is an opportunistic, fast growing, annual species.

Distribution: European North Atlantic coasts and the Mediterranean.



Photo: M.D. Guiry

Fig. 2.2

Species: *Alaria esculenta*

Family: Alariaceae

Characteristics: Short stipe, long, smooth blade with a flexible mid-rib, plant length up to 4 metres, perennial. *Alaria esculenta* with its flexible and smooth thallus is well adapted for inhabiting very exposed sites on the shore.

Distribution: Amphioceanic.

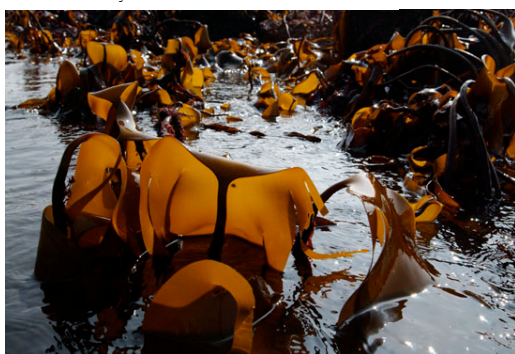


Photo: M.D. Guiry

Fig. 2.3

Species: *Laminaria hyperborea*

Family: Laminariaceae

Characteristics: Stiff, upright stipe with a rough surface, leathery, digitate blade, plant height 2-3 metres, perennial. In comparison with the two other laminarian species, *L. hyperborea* is the one most prone to desiccation.

Distribution: Eastern North Atlantic coasts.

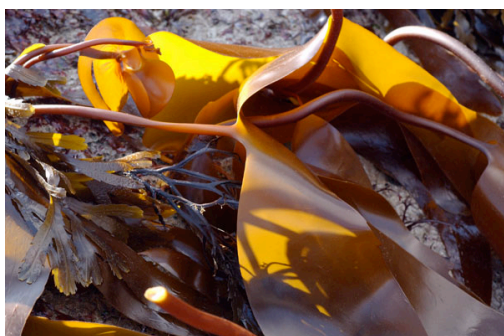


Photo: M.D. Guiry

Fig. 2.4

Species: *Laminaria digitata*

Family: Laminariaceae

Characteristics: Smooth, flexible, oval stipe, leathery, digitate frond, plant height about 2 metres. The flexibility of the stipe and blade allows growth at wave-exposed sites.

Distribution: Amphioceanic.

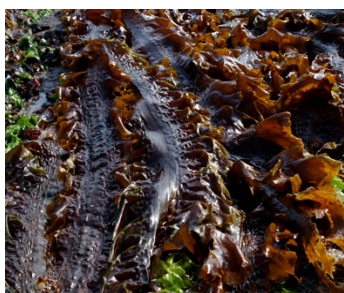


Photo: M.D. Guiry

Fig. 2.5

Species: *Laminaria saccharina*

Family: Laminariaceae

Characteristics: short flexible stipe, long blade, undulated at the margins, blade length up to 3 metres.

Distribution: Amphioceanic.

The other kelp species do not form extended monospecific stands but are found in patches in certain areas on the shore. *Alaria esculenta* inhabits very exposed sites in the upper sublittoral although it can also be found in deeper water but only in places where *L. hyperborea* is lacking due to very strong wave action. In contrast, *L. saccharina* grows in more sheltered areas in the upper sublittoral, mainly because its undivided blade is less tolerant to mechanical stress. This species is often found in bays with a mixed substratum of sandy patches and smaller rocks or stones. *Saccorhiza polyschides* inhabits medium to high exposed sites in the upper sublittoral zone. It is the only annual kelp species. *Saccorhiza polyschides* is an opportunistic alga with a high quantitative light demand (Norton & Burrows, 1969a). It occupies and develops quickly in denuded areas due to its high growth rate and thus may out-compete other kelps (see Chapter 3.4).

Table 2.1 summarises some main characteristics of the five kelp species, which are native to Ireland. It shows the geographical as well as the vertical distribution on the shore. The life span gives some indication of growth rates, which can be expected, because generally growth is negatively correlated to the life span of a species. This is an important factor to consider when developing management strategies.

Table 2.1

Kelp species, their distribution habitat and lifespan.

Species	Geographical distribution	Depth	Exposure	Life span (years)
<i>Laminaria hyperborea</i>	Iceland, Russian coast (Murmansk) - Portugal	Mid-sublittoral*	Medium - high	10 - 15
<i>Laminaria digitata</i>	Spitsbergen - Brittany/France	Upper- mid-sublittoral	Medium - high	3 - 5
<i>Laminaria saccharina</i>	Spitsbergen - Portugal	Upper- mid-sublittoral	Medium	2 - 5
<i>Saccorhiza polyschides</i>	South Norway - Morocco	Upper- mid-sublittoral	Medium - high	1 - 1.5
<i>Alaria esculenta</i>	Spitsbergen - Brittany/France	Upper- mid-sublittoral	High - very high	4 - 5

* The zonation within the sublittoral is defined according to Lüning 1990: Upper sublittoral referred to the zone from one to a few metres below mean water, which is exposed at extreme low tides. Mid-sublittoral is never emerged. It is characterised by a dense vegetation of kelp, forming a closed canopy down to a depth reached by about 5% of the surface light. The zone below this depth, where light cannot sustain a closed kelp canopy, is referred to as lower sublittoral. It extends to the lowest limit of algal vegetation where the light level is as low as 0.05% of the surface irradiance in the tropics.

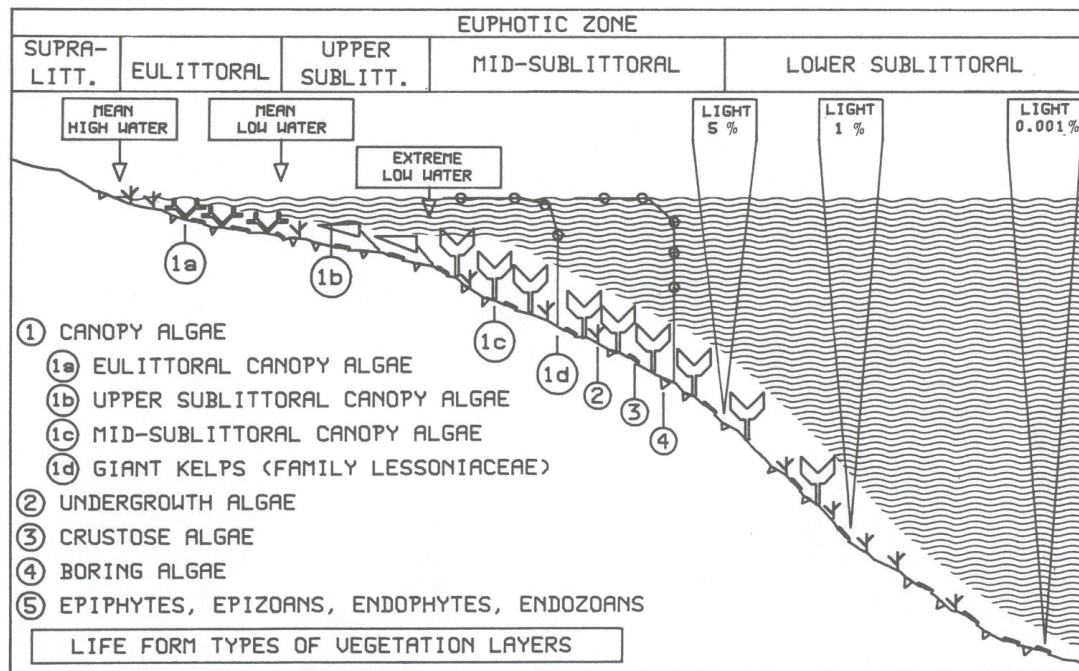


Figure 2.6 Scheme of algal life-form types and their distribution within the euphotic zone. Representatives of group 5 occur throughout the whole euphotic zone and are not illustrated in the figure. The deepest crustaceous red algae were found at 268 m or at 0.001% of surface light, but only in the clearest water (from Lüning, 1990).

2.2 Life cycle of kelps

Kelp species have a heteromorphic life cycle with alternating phases of a macroscopic, asexual, diploid ($2n$) sporophyte and a microscopic, sexual, haploid ($1n$) gametophyte. The mechanisms of reproduction are similar for all members of Laminariales.

Within the genus *Laminaria*, sori, from which the asexual haploid zoospores are released, are formed on the blade of the plants. In mature plants of *Laminaria* species, sori cover most of the blade. In contrast, *S. polyschides* and *A. esculenta* develop special organs for asexual reproduction. In *S. polyschides*, new tissue grows out near the base of the stipe leading to the convoluted form of the lower part of the stipe where the unilocular sporangia develop. *A. esculenta* develop unilocular sporangial sori on specially formed blades, so-called sporophylls, just above the holdfast. The development of reproductive organs at the base of the stipe is advantageous as reproduction will still take place if the blade is removed (e.g. by heavy storms, grazing, harvesting), whereas in *Laminaria* species the opportunity for reproduction would be lost if the blade is destroyed. On the other hand, *Laminaria* species have the advantage that the range of dispersal might be greater because zoospores are released from higher in the water column and thus the chance of reaching new areas for colonisation would be greater.

Asexual reproduction via the dispersal of zoospores is an important mechanism allowing species to extend their habitats and to reach new ones, as well as to escape prevailing unfavourable environmental conditions (Santelices, 1990). Additionally, dispersal and subsequent sexual reproduction is also a mechanism that promotes genetic diversity within populations (Reed *et al.*, 1988).

After release from the sporangia, spores of kelp species stay in the water column for about 24 hours (Henry & Cole, 1982). The major influencing factors for dispersal are wave action and current. The dispersal range of marine algal spores is generally no more than tens of metres from the parent plant and the number of spores decreases exponentially with increasing distance from the source (Chapman, 1986). However, investigations into the dispersal range of *L. hyperborea* spores in Norway revealed that the range is at least 200 metres from the parent plant (Fredriksen *et al.*, 1995). Dispersal of spores is vital, for example, the reforestation of barren areas, which can be caused by harvesting or heavy grazing by the green sea urchin *Strongylocentrotus droebachiensis* (see Chapter 4.4).

Although kelp zoospores have two flagella and thus are motile, this has little influence on the dispersal range, but may greatly enhance the spore's ability to find a high-quality micro-site on which to settle and may be useful to find a nearby mate (Norton, 1992; Reed, *et al.*, 1992). After attachment to the substratum, the spores germinate. Zoospores released by *Laminaria* species in autumn and winter apparently form the first cell of the gametophyte after settlement, which then lies dormant in the sublittoral zone for the following months. In February, when light conditions are favourable, the gametophytes finish their vegetative growth phase during a one to two week period and become fertile (Lüning, 1990). For successful fertilisation female and male gametophytes must grow within a certain distribution range. Fertilisation among kelps is synchronised by a combination of environmental factors. In order to increase the probability of fertilisation, the egg releases a sexual attractant (pheromone), which triggers the release of spermatozoids and guides the way to the egg. However, the range of the attraction by the pheromone does not exceed one millimetre (Müller, 1981). After fertilisation, the sporophyte starts to develop, thus starting a new phase of the life cycle.

The main time of sorus formation and subsequent zoospore release in the kelp species under consideration here is between autumn and winter (Table 2.2; Lüning 1990). However, there may be regional differences as shown for *L. digitata* with two periods of asexual reproduction in Brittany, or a peak time for zoospore release during an extended period, in which reproduction is taking place.

Table 2.2

Reproduction times for European Atlantic kelp species. General reproduction times valid for European coasts and peak times of reproduction for specific coast lines (blue) are given.

Species	Reproduction time	European coasts	Author
<i>Laminaria hyperborea</i>	October - April January	General Norway	Kain, 1975 Fredriksen <i>et al.</i> , 1995
<i>Laminaria digitata</i>	Autumn - winter June/July and October/November	General Brittany/France	Lüning, 1990 Arzel, 1998
<i>Laminaria saccharina</i>	Autumn - winter	General	Lüning, 1988
<i>Saccorhiza polyschides</i>	Autumn - winter September/October	General Brittany/France	Arzel, 1998
<i>Alaria esculenta</i>	Autumn - winter February - March	General Ireland	Widdowson, 1971 Kraan, 2000

2.3 Growth of kelps

Kelp plants consist of a blade or lamina, a stipe and a holdfast by which they are attached to the substratum. This root-like structure serves as an anchor only and has no known function in nutrient uptake. The major zone for longitudinal growth, the meristem, is located between the stipe and the lamina. Despite frequent loss of tissue of the apical end of the blade due to mechanical stress by wave action and increasing age of the blade, new tissue is continuously produced by the basal meristem (Kain, 1976a). The meristem, however, is not active at the same rate over the whole year. Growth in kelps is seasonal (Lüning, 1993). Highest growth rates occur from early spring to late summer. In autumn growth rates decrease in order to build up reserves in form of storage carbohydrates (Chapman & Craigie, 1978; Lüning, 1979). These are metabolised in late winter, enabling perennial species to start growth at a time when the light conditions are still not favourable for high photosynthetic activity to support growth. This results in making them more competitive in comparison to those species, whose stimulus for growth depends on a higher level of irradiance, e.g., *S. polyschides*.

Growth rates of *L. digitata* and *L. saccharina* decline at the end of summer but do not cease completely, in contrast to *L. hyperborea*. In *L. hyperborea* the growth period ends in late summer. In February, when growth starts again, a new meristem is activated below the old one, which leads to the distinctive lace-like form when the new lamina is growing out pushing the old one in front (Fig. 2.7). Growth in kelps is controlled by an endogenous clock, which governs the seasonal rhythm of elongation (Lüning, 1993; Schaffelke & Lüning, 1994).

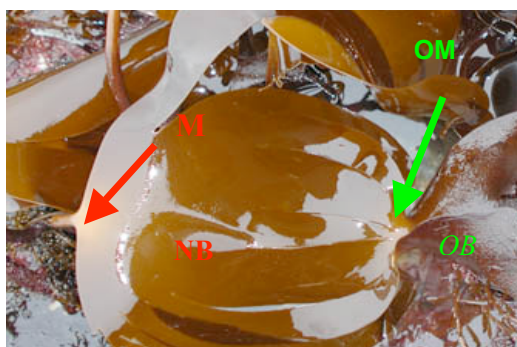


Fig. 2.7 *Laminaria hyperborea*: The meristem (M, red arrow) is distinguishable from the other tissue by the light brown colour. NB = new blade, OB = blade from the previous year, OM = meristematic zone of the previous year. (Photo: www.qualite-info.fr)

The actual growth rates depend mainly on environmental factors, such as light, temperature and nutrient availability. Average annual growth (i.e. increase in length) for *L. digitata* and *L. hyperborea* have been shown to be about 40 - 65 cm and 35 - 70 cm, respectively (Pérez, 1969; Lüning, 1990; Sjoetun, 1995; Sjoetun, *et al.*, 1998).

2.4 Flora and fauna associated with and ecological significance of kelp forests

Kelp forests of cold-temperate regions around the world represent highly diverse, dynamic and complex ecosystems (Mann 1982; Dayton 1985; Birkett *et al.* 1998).

They are characterised by:

- High productivity
- High biodiversity and strong interaction among species communities
- Provision of habitat, food and shelter
- Provision of reproduction and nursery grounds for other species
- Modifying wave action and bottom currents

Productivity of kelp forests

The large brown algae of kelp forests inhabit an environment of vigorous water movement and turbulent mixing. This allows very high levels of nutrient uptake, photosynthesis and growth. The most productive kelp forests are found along the North American Pacific coast, and rival the productivity of the most productive terrestrial systems (Velimirov *et al.*, 1977). *Laminaria*-dominated communities of the European coasts have an annual productivity of approximately 2 kg carbon per m². This is higher than, for example, temperate tree plantations or grasslands with a productivity of generally less than 1 kg carbon per m² (Thomas, 2002).

Flora and Fauna associated with kelp beds

The biodiversity of kelp forests is very high in comparison to other algal communities. Through their three-dimensional structure kelp species provide additional substrata for a broad spectrum of macro and micro flora and fauna. The diversity and number of individuals, however, is higher in *L. hyperborea* beds than in *L. digitata* stands (Schultze *et al.*, 1990). This might be attributed to the higher mechanical impact due to the fact that *L. digitata* grows higher on the shore and is therefore more exposed to surf and also occasional emersion. Additionally, the smooth and flexible stipes of *L. digitata* are generally not colonised by other species.

All parts of kelps (holdfast, stipe and blade) function as substrata and with increasing age of kelp plants the number of associated species and abundance increases significantly (Rinde *et al.*, 1992). The epiphytic flora, generally found on the stipes of *L. hyperborea*, comprises mainly of red algal species, such as *Palmaria palmata*, *Phyllophora* spp. and *Delesseria sanguinea* (Whittick, 1983). Besides these leafy species, a substantial number of filamentous, branched species, such as *Polysiphonia* and *Ceramium* species and coralline encrusting algae, such as *Lithothamnion* spp., can be found (see Appendix 1 for algal and invertebrate species found on *Laminaria* on the west coast of Ireland). The epiphytic flora forms an additional microhabitat for various invertebrates, but also shows changes in biovolume over the course of the year (Christie 1995; Whittick 1983).

The fauna associated with kelp are both sessile and mobile macrofauna. Sessile macrofauna comprises, for example, various species of sponges, anemones, bryozoans and sea squirts. The dominant groups of the smaller mobile fauna, in terms of species and number of individuals, are amphipods and gastropods, as studies on different European coasts have shown (Jones, 1971; Schultze *et al.*, 1990 and Christie, 1995). Some of the invertebrates are found preferentially associated with the kelp stipe epiflora (e.g. gastropods and amphipods), and others, such as polychaetes, tanaids, isopods and numerous amphipods, are found to be restricted to the holdfast. In contrast, some species were ubiquitous showing no habitat preference. Numerous species are found not to display fidelity to individual kelp plants but to be highly mobile and move between plants. High mobility is probably caused by strong competition for space and food, and has also implications for re-colonisation of recovering kelp beds after harvesting (Norderhaug *et al.*, 2002). Besides the sessile marine organisms and mobile species that are directly associated with kelp, other species such as seals and sea birds intermittently use the kelp beds for food.

Kelp forests for habitat, food and shelter

Kelp forests not only provide a habitat for small macrofauna directly associated with the kelp plants but, they are also important habitats for larger resident animals, such

as crustaceans, sea urchins, starfish and others which visit the kelp beds in search of prey and/or shelter, such as various species of fish (Gordon 1983; Christie 1995). Information especially on larger fish species using kelp beds as feeding grounds is limited, probably due to the methodological difficulties in recording them. However, stomach investigations of some economically important fish have shown that cod (*Gadus morhua*), pollack (*Pollachius pollachius*) and saithe (*Pollachius virens*) consume considerable proportions of their food from kelp forests (Hoeisaeter & Fossaa, 1993). The diverse macrofauna associated with kelp beds provides a food source for a range of higher trophic levels within the kelp forest and in adjacent communities. However, not only the kelp associated fauna but also the seaweed itself represents an important food source for a number of species. Echinoderms, molluscs and herbivorous fish graze on kelp. Additionally, kelps produce considerable amounts of detritus and dissolved organic matter. Broken parts of kelp lamina are consumed by, for example, amphipods, crustaceans and sea cucumbers. Small fragments represent a rich food supply for a broad spectrum of invertebrates, such as mussels, tunicates, anemones and polychaetes, within the kelp forest and in the intertidal and lower subtidal (Mann, 1982 and Thomas, 2002).

Kelp beds as reproduction and nursery grounds

Kelp forests are also reproduction and nursery grounds for fish. They provide shelter against predators and protection against wave exposure, thereby offering good feeding grounds. Saithe, for example, use shallow kelp beds as their main nursery grounds (Hoeisaeter & Fossaa, 1993).

Modification of wave action and bottom current

Dense kelp stands have a considerable effect on reducing wave impact and modifying bottom currents. Seaweeds may have a similar function in protecting coastlines against wash out of loose material during storms in a similar way to terrestrial vegetation that protects slopes and embankments against erosion. (Andersen *et al.*, 1996 and Mork, 1996).

COMMERCIAL KELP HARVESTING IN FRANCE

France and Norway are the only European countries where kelp (*L. digitata* and *L. hyperborea*, respectively) is currently harvested in large quantities. In these countries, the raw material is used for alginate extraction by the domestic hydrocolloid industry. Both countries have developed special harvesting machinery, which meets the specific requirements with respect to kelp species and coastal conditions. And specific management schemes have been developed, which match the characteristics of the kelp species harvested in order to sustain natural resources.

3.1 Harvesting method of *Laminaria digitata*

France has a long history of seaweed harvesting. Kelps were traditionally harvested by hand and transported from the shore by horses. Between 1950 and 1960 *L. digitata* was used for iodine extraction. After the decline of this industry, the French phycocolloid industry developed and *L. digitata* was used as the raw material for alginate extraction. With increased demand, harvesting became mechanised in order to be effective. The equipment, which is still used today, was a further development of a tool used in the 1950s. It consisted of a sickle fixed on to a 3 - 4 metre long pole. By rotating the pole with the sickle, *L. digitata* was wrapped around the sickle and pulled up to the surface. Using this method harvests averaged 1.5 - 2 tonnes wet weight per boat per day. The principle of this tool was adopted to develop the mechanical, so-called Scoubidou apparatus (Kaas, 1998).

The fishing boats have a defined size of 8 - 12 metres in length. They are equipped with one or two hydraulic scoubidous and have a loading capacity of 10 - 20 tonnes raw material. The scoubidou can pull up about 10 kg per extraction, which takes about 30 seconds. By employing the scoubidou method, kelp plants smaller than 60 cm (i.e. plants younger than 2 years) are thought to be too small to be caught by the hook and remain to develop into the crop for the following year (Kaas, 1998). Pérez (1969) compared the methods of manual cutting of kelps and the use of the scoubidou and found no obvious differences in the recovery time of harvested *L. digitata* populations.

3.2 *Laminaria digitata* harvest and regulation of harvesting effort

Between 1960 and 1982 *L. digitata* harvesting increased steadily from 15,000 tonnes (wet) to 30,000 tonnes *per annum*. In response to a moderate demand for alginates on the world market, restricted storage capacities for harvested raw material and the fear of over-exploitation, harvesting quotas were established. In 1983, these quotas were extended and within six years the harvesting of *L. digitata* increased to 60,000 tonnes *per annum*. This production volume remained generally stable until today, although the production is insufficient to meet the demand of the industry. An additional 30,000 tonnes *per annum* would be required and various attempts have been made to address this problem (Kaas, 1998; see Chapter 3.4, "Environmental impact of kelp harvesting").

At present, the French alginate industry involves two companies: Danisco Ingredients International and Degussa Systems. Based on an exclusive agreement between the companies and the trade union, the landings of *L. digitata* are sold in equal parts to the two companies (P. Arzel, IFREMER, 2003, pers. comm.). The companies however also import additional raw material for alginate extraction from other countries, such as Chile and South Africa.

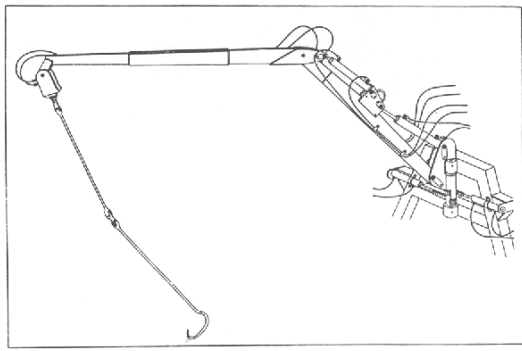


Fig. 3.1. View of the hydraulic arm (above), which is installed on the fishing boat. The iron hook at the end of the arm is called “Scoubidou”. Right: A harvesting boat in action (from Arzel 1998 and Kaas 1998).

Regulation of harvesting

In France, there are two levels of regulation for the harvesting of seaweed. The first level is defined by the State, giving the legislative framework with respect to the utilisation of natural marine resources and fishing licences in general. At the second level, which involves the industry and fishermen, detailed regulations are defined comprising, for example, harvesting times, quotas and number of licences. The body of competence at this level is the "National Syndicate of Marine Algae" ("Marine Algae Interprofessional Committee" until 1992). The Syndicate is formed by members of the industry, fishermen, and scientific advisers, which are organised at a regional and local level within the fisheries organisation ("Commission algues marine du comité régional des pêches maritimes et des élevages marins de Bretagne" together with local committees). Regulations for harvesting are developed on the basis of self-regulation to ensure the sustainability of natural resources. Management propositions developed by the Regional Committee of Fisheries are transferred to the Ministry of Fisheries in order to control their legality. Scientific advice is provided by IFREMER (French Research Institute for Exploitation of the Sea) as part of its responsibilities (Arzel, 1998). In order to give appropriate advice, a bi-monthly survey of the kelp beds during the harvesting season is conducted by IFREMER. Parameters, such as mean plants per m², mean weight per m², size composition and recruitment are investigated at two stations along the coast of Brittany. Accompanying research programmes comprise studies of the polyphenolic concentration in *L. digitata* and genetic biodiversity (P. Arzel, 2003, pers. comm.). Upon the request of the Regional Committee of Fisheries, special research programmes (e.g. environmental impact studies of *L. hyperborea* trawling) are also carried out by IFREMER. In these cases, the commission submitting the request has to pay the costs of the study.

Harvesting quotas and raw material prices

Harvesting quotas are bound to the harvesting vessel. Depending on the size of the boat and the equipment (one or two scoubidous), the boats are allowed to land between 12 - 18 tonnes of *L. digitata* per day and 1,000 - 1,500 tonnes *per annum*. There are certain ports along the coast of Brittany where the boats land their harvest. In the ports the raw material is loaded onto trucks. Each loaded truck has to drive over

a balance to register the weight of the biomass harvested by the particular boats, before transporting the raw material to the processing companies.

The prices for the raw material are negotiated by the fishermen and the industry before the start of the harvesting season and are valid throughout the season. Prices, however, are re-adjusted for each boat at the dockside to take into account the actual quality in terms of purity of the crop, i.e. the proportion of *S. polyschides* within the *L. digitata* harvest and stones pulled up with the crop (see Chapter 3.4). At present, the price for a single tonne (wet) of *L. digitata* varies between €29 - 39 (P. Arzel, 2003, pers. comm.).

Regulation of harvesting times

- The official harvesting season is from May 15th - October 15th. During the winter months, a few boats (2 - 5) are allowed to harvest seaweeds, in order to sustain a basic supply for the domestic alginate industry.
- During the whole harvesting season, only one harvesting trip per boat per day is allowed.
- The number of harvesting days per week is regulated as follows:
 - 1st week of the harvesting season: 2 days per week
 - 2nd & 3rd week of the season: 3 days per week
 - Until June 15th: 4 days per week
 - Mid June until the end of the season: 5 days per week

This regulation is applied to take into account that *L. digitata* is still growing at the beginning of the harvest season (until mid June) and therefore allow further increase of standing stock by limiting days of harvest. Additionally, in June/July *L. digitata* becomes fertile and may release spores before being harvested.

Licences for harvesting Laminaria digitata

Each boat requires a licence for harvesting. This is issued by the government annually and is linked to the boat and the skipper. The licence costs €100 per annum and is generally renewed without difficulties. It is not transferable between boats or skippers. Between 1985 and 1996, on average 72 boats were licensed for kelp harvesting with a maximum number of 76 boats in 1990 and 1991. Thereafter the number of authorised licences has decreased. In recent years, about 60 boats were licensed to harvest *L. digitata*. After fishermen have harvested the total annual biomass, which they are allowed to land during the open season, they convert their boat to dredge for scallops and mussels (P. Arzel, 2003, pers. comm.).

Harvesting areas

Dense beds of *L. digitata* are found along the western part of Brittany including the islands off the mainland. The resource of *L. digitata* in Brittany is estimated to be 300,000 tonnes with a standing stock of about 60 tonnes per hectare.

The coast is divided into sectors to facilitate the allocation of harvesting vessels and also monitoring activities. These sectors are under the auspices of the Local Committees for Fisheries. By decree, the kelp harvesters by having a valid licence are allowed to harvest everywhere, but fishermen/boats are usually allocated to certain harvesting areas within the sectors. This measure is applied to balance available resources and fishing effort.

The fishing boats harvest *L. digitata* from beds at 3 - 5 metres water depth. The tidal range off the coast of Brittany is about 13 metres, which, combined with strong currents, influences the harvest activity.

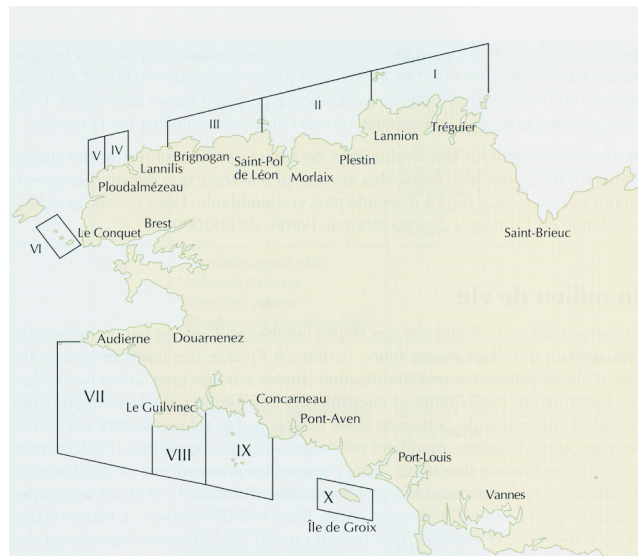


Fig. 3.2 Harvesting boats are allocated sectors on the coast of Brittany (Arzel 1998).

Fallow periods

In France there are no official regulations with respect to fallow periods for *L. digitata* beds. Consequently, most kelp beds are harvested year after year. Because *L. digitata* was found to have a sufficient recruitment and growth, no recovery time was necessary in the past, as frequent surveys have shown. In recent years, however, *L. digitata* beds are declining (see Chapter 3.4). The introduction of fallow periods would be advisable but this would require an expansion of the areas, in which harvesting could take place. As a result, the boats would have to go further out off the coast, which would be more costly and time consuming. However, attempts have been made to locate new kelp beds for exploitation using different methods ranging from satellite imaging, sonar and side scan to underwater monitoring (Kaas, 1998). In addition, methods have been tested to compensate for longer journeys to the harvesting grounds by using transport boats to take over the crop from the harvesting vessels to allow a second harvest in order to optimise economical efficiency (Arzel, 1998). The only other alternative, if fallow periods were to be introduced, is the reduction of the number of fishing boats and consequently production rate.

In certain harvesting sectors, where only a small number of harvesting boats are operating in a sufficiently large area (e.g. sectors VII and VIII with two licensed harvesting boats each, see Fig. 3.2), local fishermen have introduced self-management and fallow periods of 1 - 2 years (P. Arzel, 2003, pers. comm.).

3.3 Harvesting of *Laminaria hyperborea* in France

Investigations into new resources for alginate production became necessary due to the recent decline of *L. digitata* beds. *Laminaria hyperborea* is the only other potential candidate for alginate extraction beside *L. digitata*. Natural resources of this species are estimated to be 5,000,000 tonnes along the coast of Brittany with beds extending from 3 to 30 metres depths below mean low water (Kaas, 1998). For many years, *L. hyperborea* stipes washed upon the shore were collected and used for alginate extraction having contributed a biomass of 2,100 tonnes in 1987 and 800 tonnes in

1996 (Kaas 1998). Mechanical harvesting of *L. hyperborea* was introduced in 1995 using the same machinery (kelp trawler) as in Norway (see Chapter 4). The production is about 2,500 tonnes (wet) per annum. For *L. hyperborea* a similar management strategy as in Norway is applied allowing a five-year fallow period (P. Arzel, 2003, pers. comm.).

3.4 Environmental impact of mechanical *Laminaria digitata* harvesting

Since the introduction of the scoubidou, *L. digitata* exploitation has been monitored frequently, although the number of reports available to the public is limited. However, the information that was gathered and the effects of mechanical harvest on the *Laminaria* beds seemed to be variable. The growth and age distribution of *L. digitata* even in unexploited areas was also variable (Kaas, 1998).



Fig. 3.3. *Laminaria digitata* field after harvested by a scoubidou (from Arzel 1998).

In general, frequently harvested *L. digitata* beds are showing a shift towards homogeneity of age classes. With the scoubidou method, in general, plants longer than 60 cm (or 2-5 years old) are removed. The one-year old plants are left to grow out for the next year's harvest together with the remaining older plants. On average, 30% of the population of a kelp forest is harvested. Because the beds are frequently harvested, over time the percentage of the 3 - 5 year old plants decreases, and consequently the age structure within kelp populations is becoming more homogenous by consisting mainly of 1 - 2 year old plants after several years of harvesting. The rejuvenation of populations affects also the overall biomass of the stocks because highest biomass per plant is found in 3 - 4 year old plants (Arzel, 1998).

Recruitment may also be affected. *L. digitata* shows two phases of fecundity, one in June/July and another in October/November resulting in two periods of recruitment, one in October/November and the other in March - May (recruits are defined as plants < 15 cm; Arzel, 1998). The recruits are found to develop differently with those derived from spores released in autumn showing a significantly faster growth rate compared to those derived from spores released in spring (Pérez, 1971). Obviously, the growth of the latter is suppressed by shading from older plants because the density of plants and the biomass of stocks are highest during summer to autumn. In contrast, recruits from the spore dispersal event in autumn are developing at a time of the year, when the overall biomass of the kelp beds is decreasing. In autumn/winter, older plants lose a high proportion of their old parts of the lamina. This non-growing, distal tissue becomes weakened after spore release, grazing and fouling (mainly by bryozoans), and consequently breaks off. Additionally, the adherence of the holdfast of older plants to the substratum loosens. For this reason, manual harvesting of *L. digitata* was traditionally carried out in autumn, when it was easier to pull off the plants from the substratum. As a consequence of the decreasing adherence of the holdfast, whole plants get dislodged during autumn and winter storms. Even under unexploited conditions, the overall annual mortality of kelps in beds can be up to 50% (Arzel, 1989).

During recent years kelp beds have been affected by another factor. In certain areas off the coast of Brittany, the homogeneity of *L. digitata* beds is increasingly disturbed by a strong development of *S. polyschides*. The increase in abundance of this species is leading to economic losses for the fishermen, as a high proportion of *S. polyschides* in the harvested crop lowers the value significantly. Depending on the season, *L. digitata* has an alginic acid content of 20 - 45% of dry weight, with highest alginic acid contents in autumn (Indergaard & Minsaas 1991). In contrast, *S. polyschides* has an average alginic acid content of about 10% of dry weight (A. Critchley, Degussa, 2003, pers. comm.). In recent years, the industry has started to reject *Laminaria* crops containing an apparent proportion of *S. polyschides* of over 50% and is paying less than the negotiated price for a harvest not showing the expected homogeneity. This means that in some cases harvesters has to discharge whole boat loads back into the sea.

The reasons for the increasing abundance of *S. polyschides* are unclear. This kelp, as mentioned earlier, is an opportunistic, fast growing, annual species. In a period of 8 months (from early spring to autumn), it can reach a size of up to 3 metres in length (Norton & Burrows, 1969b). It grows in the upper and mid-sublittoral, thus competing with *L. digitata* and *L. hyperborea* respectively for space. In contrast to the *Laminaria* species, it also grows on disturbed substrata such as unstable boulders and smaller rocks (Lüning, 1990). It rapidly colonises free space, which, for example, is created after harvesting. Due to their rapid growth, young *Saccorhiza* plants quickly shade developing *L. digitata* sporelings, which are consequently arrested in their growth or displaced (Arzel, 1998). In autumn/winter *Saccorhiza* plants decay and are removed from the substratum by storms and heavy water motion. With the reduction of shading canopy algae, young *Laminaria* sporophytes can resume development, although decreasing light levels in winter result in low growth rates.

Fast growth and competition with other *Laminaria* species do not explain sufficiently the increased occurrence of *S. polyschides* in recent years. Slight changes in water temperature may play an important role. As described in Chapter 1, *L. digitata* as a cold-water species reaches its southern limit of distribution in Brittany. In contrast, *S. polyschides* is a warm-temperate species with a geographical distribution from South-Norway to Morocco. Thus, even minimal increase in the average water temperature, which is assumed for the coastal waters off Brittany, may positively affect growth and reproduction of *Saccorhiza*, whereas it may have an adverse effect on *L. digitata*. Differences in temperature responses are given in Table 3.1.

Table 3.1: Temperature responses of *Saccorhiza polyschides* and *Laminaria digitata*.

Species	Optimal growth temperature (°C) (sporophyte)	Upper survival limit (°C) of gametophytes	Temp. limits for formation of gametangia* (°C)	Author
<i>Saccorhiza polyschides</i>	23	25	5 - 23	(Norton 1977)
<i>Laminaria digitata</i>	10 - 15	22 - 23	below 18	(Bolton & Lüning 1982)

[* gametangia are the reproductive organs (spermatangia and oogonia) developed by gametophytes]

The decline of standing stocks of *L. digitata* may also be the result of over-exploitation. In most areas off the coast of Brittany kelp beds are harvested without allowing the standing stock to recover between the harvesting seasons. Potential factors leading to an exhaustion of stocks may be:

- Removal of more than 30% of the standing stock during a harvesting period, together with natural losses of plants, can remove up to 50% of the population (Arzel, 1998).
- Unintended removal of first-year plants, which would normally be spared, due to intensive harvesting in one area (R. Kaas, IFREMER, 2003, pers. comm.).
- Narrowing the age class distribution to 1 - 3 year old plants and thereby reducing the overall output of spores and consequently success of recruitment. *L. digitata* becomes fertile in the second year by developing sori (special areas for the production of spores; see Chapter 3.2) on the blade. The area on the blade covered by sori is about 50% in third-year plants. Spore production is highest in four-year plants with sori covering up to 80% of the blade (Arzel, 1998). In older plants, growth rates decline and sorus development and subsequently spore production decreases as well. The maximum age of *L. digitata* is 3 - 5 years.

The introduction of fallow periods of one to two years may improve the recovery of *Laminaria* beds significantly by increasing the average age plants within the populations as well as recruitment. It is also seen as a method to allow *L. digitata* to replace *S. polyschides*, because the latter is an annual species, which dies off in winter. Due to its slower growth compared to *S. polyschides*, it is assumed that it may take 2 - 3 years for *L. digitata* to successfully re-colonised areas, in which *S. polyschides* had been developed previously (P. Arzel & R. Kaas, 2003, pers. comm.). At present the, economic pressure for harvesters to retain their income, constant demand for raw material, and limitation of availability of accessible kelp beds hinders the introduction of fallow periods.

COMMERCIAL KELP HARVESTING IN NORWAY

4.1 Harvesting of *Laminaria hyperborea*

Norway has a long tradition of harvesting seaweeds similar to that of France and Ireland. Throughout history, various seaweeds were utilised for different purposes. Kelps became economically important in the production of potash for soda between the 17th and 19th centuries (Jensen, 1998). During the World War II, the Norwegian phycocolloid industry was established. In the early phase of alginate production, *L. digitata* was selected for utilisation in preference to *L. hyperborea*, because of its high quality of alginic acid and low content of phenolic substances, which requires only mild bleaching to give a snow-white end product (Jensen, 1998). In addition, *L. digitata* could be hand-harvested at low tide. In 1969 and 1970, *L. digitata* production reached 15,000 tonnes (wet). In the 1950s and 1960s extensive biomass measurements of the main sublittoral species were conducted at representative sites along the Norwegian coast from the south to east Finland in the far north. On the basis of these data, Indergaard & Jensen (1991) estimated the total biomass for sublittoral phaeophytes for the Norway to be a minimum of 15 million tonnes, of which at least 10 million tonnes was *L. hyperborea*.

With the expanding market for alginate, the Norwegian phycocolloid industry had to turn to larger raw material resources and to develop means for more efficient harvesting methods. In the 1950s, *L. hyperborea* stipes were collected from the seashore and in 1964 the first trials with a mechanical device, a seaweed dredge, were conducted. The equipment was further developed and constantly optimised in the following years by the alginate industry.

For harvesting, a seaweed dredge was developed, which is fixed to a crane on specially designed boats or fishing vessels. The dredge is towed through the kelp beds cutting the plants 5 - 20 cm above the holdfast. In practice however, entire plants including holdfast are pulled off the substratum (Fig 4.1., Briand, 1991).

Modern dredges, developed in the 1970s, have a carrying capacity of two tonnes per haul with one haul taking 0.5 - 2 minutes. The harvesting boats are different size with a loading capacity of 30 - 150 tonnes. They are operating at depths between 2 - 20 metres (Jensen 1998; Vea 2001, unpubl.).



Fig. 4.1 Norwegian cutting dredge (above left). Special designed boat (dredge trawler; above) with a crane, to which a dredge is installed (from Arzel 1998).

4.2 *Laminaria hyperborea* harvest and resource management

Between 1973 and 1984 the annual production of *L. hyperborea* steadily increased from 118,000 to 170,000 tonnes (Jensen, 1998). In recent years, between 140,000 and 180,000 tonnes *per annum* are harvested (Vea 2001, unpubl.).

Exploitation of kelp is limited by the Fisheries Authorities (in consensus with the industry) to selected areas in four coastal counties along the south and southern west coast between 58° and 64° N (Fig. 4.2). There are four pre-treatment centres along the coast, where the raw material is landed. Here the kelp is cut, treated with formaldehyde and stored in silos, until it is brought to the main alginate extracting factory in Haugesund (Jensen, 1998).

The alginate industry in Norway comprises only one company, which is FMC BioPolymer AS (former Pronova Polymers). In contrast to France, in Norway the harvesters are employed directly by the alginate processing industry.

Resource management

With the invention of efficient mechanical harvesting techniques and consequently the high removal of biomass, it became necessary to implement official regulations. At this stage, the University of Bergen conducted the first investigations on re-growth of *L. hyperborea* and harvesters collected information when re-harvesting kelp beds (Svendsen, 1972).

The first public regulation was formulated by the Directorate of Fisheries in 1972. It was based on the "Law of Saltwater Fisheries" and mainly aimed to prevent conflicts between fishermen and seaweed harvesters. As an important step to ensure sustainability of natural resources, a 4-year harvesting cycle was introduced. The coastline, where harvesting took place, was divided into fields with a width of one nautical mile (1.85 km) stretching out several km into the sea as far as shallow rocky bottoms allow *Laminaria* forests to grow. Harvesting is arranged in such a way that a field to be harvested should not be bordered by a field harvested in the previous year. Based on scientific data, the 4-year harvesting cycle was extended to a 5-year cycle in 1992, still applies today. The biomass removed from each field is about 15 - 20%. An additional 10 - 20% of biomass is estimated to be naturally removed (Vea 2001, unpubl.).

In 1995, the responsibility for seaweed resource management was given to the Department of Fisheries, which appointed a committee to develop a long-term management plan for Norway. The committee comprised the representatives of the industry (FMC BioPolymers), the Directorate of Fisheries, the Directorate for Nature Management, the Marine Research Institute, the Norwegian Institute for Nature Research and the Norwegian Fishermen's Association. The Seaweed Management

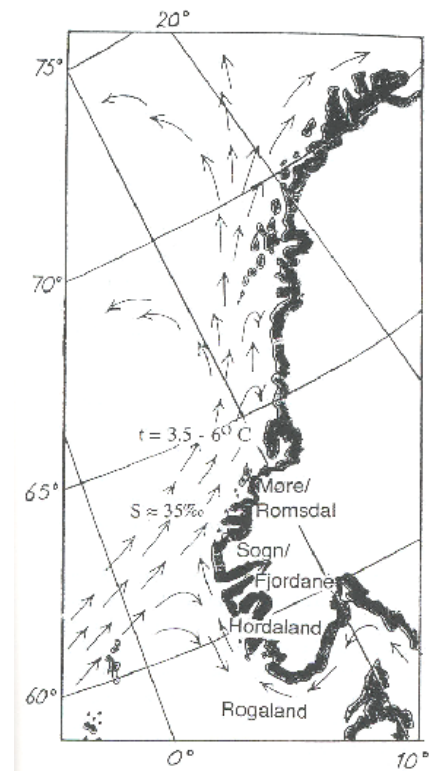


Fig. 4.2 Norwegian coast. Kelp is commercially exploited in the four counties indicated by name (from Jensen 1998).

Plan was completed in 2000 and given to the Department of Fisheries in an advisory capacity. The plan has mainly confirmed the regulations developed in 1995 and confirmed the experiences and scientific investigations. It comprises the following regulations:

- Regulations on seaweed harvesting are based on the "Law of Continental Shelf", confirming that the State owns the rights of harvesting (www.un.org/law/ilc/texts/contsh.htm)
- The Directorate of Fisheries (DOF) has the authority to regulate harvesting areas. In consultation with the Directorate for Nature Management it can permit harvesting in specific areas. The regulations comprise fallow periods and the order in which fields are harvested.
- A harvesting licence is issued for up to 5 years but only if the licensed area and neighbouring areas can withstand the harvesting impact without negative effects on the ecosystem.
- An area can be closed before the 5-year licence expires if unexpected consequences, caused by harvesting arise. A licence can also be revoked with a permanent ban.
- The DOF can permit harvesting in non-designated, new areas if the applicant proves that the area is suitable for harvesting.
- The DOF can issue regulations with respect to harvesting equipment. The harvesting boats have to be registered by the DOF.
- At least one month before harvesting starts the owner or user of the harvesting boat has to inform the local fishery administration in which area will be harvested.
- The harvesters are obliged to write a harvesting diary stating dates, sites and quantities harvested. The harvested quantity per year has to be reported to the DOF.
- In the harvesting areas other fisheries have to give way to seaweed harvesters. (The actual situation is that the time of kelp harvesting is chosen when there is little fishery activity in the same area to avoid conflicts.)

Seaweed resources are part of the Annual Marine Reporting System of the Marine Research Institute, Bergen, which evaluates the data and elaborates a plan of research priorities (Vea 2001, unpubl.).

Other Norwegian regulations influencing seaweed harvesting

In Norway, areas for nature protection have been established and more are expected to be implemented. Seaweed harvesting is affected by these regulations to some extent. Although scientific investigations showed that seaweed harvesting is performed in a sustainable way, resulting in no obvious damage to the ecosystem, harvesting activity is excluded from some areas for precautionary reasons.

The Norwegian coastline is known for its rich seabird life and a substantial number of Seabird Protecting Areas (SPA's) have been designated. Designation has led to restrictions in seaweed harvesting. In some of the SPAs, kelp harvesting is forbidden during the breeding season, while in others all harvesting activity is forbidden.

In 2000, a national coastal zone management document was prepared by the Norwegian Parliament, in order to give guidelines with respect to nature protection measures and the utilisation of natural resources. It was an attempt to balance the interests of fishery/sea farming and conservation interests. In the final document kelp

trawling was considered an important part of coastal resource utilisation. In the document it was confirmed that conservation shall not be more restrictive than what is necessary to secure the target of the conservation measures. (Vea 2001, unpubl.).

4.3 Environmental impact of dredge-trawling of *Laminaria hyperborea*

For the alginate industry, a sustainable harvest is vital. This depends on providing enough time for regeneration of *L. hyperborea* plants. Decisions regarding the time interval of trawling are generally based on unpublished data of kelp regrowth provided by the industry itself (Christie *et al.*, 1998). However, independent investigations in the late 1980s and 1990s have already contributed to the prolonging of the harvesting cycle from 4 to 5 years (Sivertsen, 1991; Rinde *et al.*, 1992). Regrowth of kelp plants is also crucial for the recovery of the whole kelp forest ecosystem (see Chapter 2.4).

Kelp trawling removes all adult canopy-forming plants of *L. hyperborea* efficiently, while small understorey plants are left undisturbed. Due to the improved light conditions, these recruits grow out in dense stands, forming the next generation of canopy algae. Within two to four years they reach a plant height of 1 - 1.5 metres (Rinde *et al.*, 1992; Christie *et al.*, 1994). The age composition of canopy-forming kelp plants in different trawled areas showed that the recruits have developed during more than one year prior to trawling. This means that regrowth does not solely depend on the recruitment success in the year of trawling (Christie *et al.*, 1998). Intraspecific competition leads to a reduction of canopy plant density during outgrowth. However, after the fallow period of 5 years, the plant density is still higher and the age of canopy forming plants is still lower than in untrawled areas (Christie *et al.*, 1994). Differences in plant growth (length) and growth of the holdfast were found at different study sites along the Norwegian coast as well as differences in age distribution of kelp populations. With increasing latitude, growth is slower and average plant age in undisturbed kelp beds is higher (Sjoetun *et al.*, 1993; Christie *et al.*, 1998).

Laminaria hyperborea beds have been shown to recover well with respect to growth and biomass development after trawling. However, the re-colonisation of the kelp forests by associated flora and fauna after disturbance is apparently a slower process. The abundance of epiphytes, such as encrusting algae, bryozoans and foliose algae, on the stipes of kelps depends on the age of kelp plants (Whittick, 1983; Schultze *et al.*, 1990). Studies by Christie *et al.* (1998) showed that epiphytic coverage, compared to undisturbed areas, is not fully restored until six years after trawling at sites with slow growth of *L. hyperborea*. The total number of macrofauna individuals associated with the holdfast of kelp plants was low during three to four years after trawling but increased thereafter in number of individuals as well as number of species (Rinde *et al.*, 1992; Christie *et al.*, 1998). The authors concluded that the restoration of the flora and fauna community associated with kelp forests depends significantly on the recovery of kelp demography and structure. The latter may vary with environmental factors specific to a particular site. Therefore, adjustment of harvesting times might be adjusted accordingly.

4.4 Impact of sea urchins on kelp forests

During the last 20 years, destructive grazing of kelp beds by sea urchins has been repeatedly reported from areas in the northern and middle parts of Norway (Hagen, 1983 and 1995a). A range of animals eats kelp, but by far the most predatory are sea urchins. Destructive grazing of kelp beds by a range of sea urchin species in temperate regions and the subsequent creation of denuded areas, so-called barren areas, with coralline algae as the dominant flora, have been documented on a global scale in a variety of kelp habitats (Tegner & Dayton, 2000). This has severe implications with respect to food and habitat availability for species communities, which are directly or indirectly associated with kelp forests (Babcock *et al.*, 1999). Once created, barren grounds can persist for many years as sea urchins prevent the re-colonisation of kelps. On the Atlantic coast of Nova Scotia, Canada, grazing of macroalgae by the green sea urchin *Strongylocentrotus droebachiensis* is a recurrent phenomenon. The process is initiated when sea urchins form dense feeding aggregations. These move as a front through kelp beds consuming all macroalgae in their path (Breen and Mann, 1976). Grazing fronts of one to two metres in width, with peak densities of 98 individuals per 0.25 m², advancing up to four metres per month have been recorded in Nova Scotia (Scheibling *et al.*, 1999). A breakdown of sea urchin populations, caused by disease, has been observed, which can give way to the regeneration of kelp beds (Scheibling *et al.*, 1999).

In Norway, the creation of barren grounds is caused by the same species as in Nova Scotia, namely the green sea urchin *S. droebachiensis*. After the decimation of *L. hyperborea* forests in Vestfjorden in the early 1980s, sea urchin-dominated barren grounds remained for several years. Some of these barren grounds reverted back to kelp forests that lasted approximately five years before they were overgrazed by sea urchins again (Hagen, 1995a). This process of destruction, recovery and recurrent destruction of kelp beds has been observed repeatedly. In re-established kelp beds, densities of 45 - 75 *S. droebachiensis* per m² were found in 1992. One year later the kelp beds were overgrazed again (Hagen, 1995a). There is evidence that cyclical outbreaks of a nematode *Echinomermella matsi* are leading to mass mortality of *S. droebachiensis* (Skadsheim *et al.*, 1995 and Hagen, 1995b). There is a potential for re-colonisation of a barren area by *L. hyperborea*, facilitated by a wide dispersal range of *Laminaria* spores and high recruitment, if grazing pressure is removed (Fredriksen *et al.*, 1995 and Sjoetun *et al.*, 1995). Studies, in which sea urchins were manually removed from barren areas, showed that a substantial reduction in sea urchins initiated luxuriant kelp growth, while moderate removal of sea urchins was followed by a distinct succession pattern. The substratum was first colonised by opportunistic filamentous algae. Within a few weeks, these were replaced by fast growing *L. saccharina*. After three to four more years *L. saccharina* was out-competed by the slower growing, long-lived *L. hyperborea*. *Laminaria hyperborea* then became the dominant and persistent species. Increased food availability led to an increased individual growth of remaining sea urchins, but there was no increase in population either from recruitment or immigration from adjacent areas with high sea urchin densities (Leinaas & Christie, 1996).

In the northern part of Norway, where destructive grazing by sea urchins occurs, no commercial exploitation of *L. hyperborea* takes place. In 1997, however, the Directorate of Fisheries permitted restricted kelp harvesting in County Soer-Troendelag in Mid-Norway, where large areas had been affected by grazing of *S.*

droebachiensis in previous years. Harvesting activity was accompanied by a research survey to monitor regrowth of kelp and potential disturbance by sea urchins. High densities of *S. droebachiensis* were only found on barren grounds in most sheltered areas. In contrast, the edible sea urchin *Echinus esculentus* was found in harvested and unharvested areas, being present in relatively high densities (up to 15 individuals per m²) at semi-exposed sites. In some of these semi-exposed sites no regrowth of kelp was found 1.5 years after harvesting. Although *E. esculentus* was not seen to effect kelp regrowth at other sites, it was suggested that the sea urchins at the semi-exposed sites were suppressing kelp regrowth and the authors recommended that seaweed harvesting should only be practised at wave-exposed sites, where the density of *E. esculentus* was found to be low (Sjoetun *et al.* 2000).

KELP RESOURCE INVESTIGATIONS IN IRELAND

Recently, kelp resource studies in Ireland have been conducted by the Irish Seaweed Centre. Under the EU 5th Framework Programme, a CRAFT project entitled "A Novel Surfactant From Safe and Sustainable Exploitation of Seaweed; SEASURF" (Contract EVK3-CT-2000-30001, duration: 24 months) had been awarded to a consortium of five SMEs in different European countries and two research providers (Irish Seaweed Centre, Ireland, and Pera Technologies, UK). A powerful surface-active agent had been extracted from *L. digitata*, which has the potential to replace common surfactants in personal care, cleaning and de-greasing products and consequently may lead to a demand for frequent raw material supply for manufacture.

The main objectives of research, carried out by the Irish Seaweed Centre, were:

- To assess natural sustainable kelp resources in Ireland based on investigations of standing stocks of *L. digitata* and *L. hyperborea*
- To assess the effect of kelp harvesting on growth and regeneration of kelp species and to evaluate best practise for Irish kelp harvesting
- To investigate biodiversity of kelp beds and assess the impact of harvesting on the kelp forest and associated flora and fauna

The results were provided courtesy of S. Kraan and J. Morrissey (Irish Seaweed Centre) to be presented in this review and discussed in view of the potential introduction of mechanised kelp harvesting.

5.1 Study area and methodology

Study site

Experimental studies on kelp for the SEASURF project were conducted at a rocky shore called An Trá Beag (53.24N, 9.15W) near Furbo, Co. Galway. The shore is dominated by granite bedrock with sandy patches and large boulders, which are exposed at extreme low tide. *L. digitata* is the dominant species of the upper sublittoral. In the lower sublittoral, *L. hyperborea* forms kelp forests interspersed with substantial numbers of *L. saccharina* and *S. polyschides* plants, which were present in the summer and autumn months. The study area was chosen for its relative inaccessibility and the apparent absence of fishing or other activities (Fig. 5.1). Kelp sampling and measurements were carried out by snorkelling and SCUBA diving.

Harvesting procedures and growth measurements

1) Determination of biomass and growth rates

In order to determine kelp biomass, several single square metres of kelp were harvested every two months over a period of a year. *Laminaria digitata* was harvested at a depth of one metre at low water; *Laminaria hyperborea* was taken from a depth of 5 m at low water. Whole plants of each species were removed from the substratum. Wet weight of the plants per m² was measured for the calculation of standing stock.

For growth rate measurements, three randomly chosen square metres were marked for each species. Within the quadrats, four plants each of *L. digitata* and *L. hyperborea* were labelled. Growth was monitored by punching a hole into the blade and measuring the distance from the basal meristem to the hole. New tissue is formed by the meristem and consequently moves the hole in distal direction (see Chapter 2.3: Growth of kelps).

2) Flora and fauna associated with kelp plants

The flora and fauna associated with kelp was investigated by randomly sampling 10 plants of *L. digitata* and *L. hyperborean*. These were brought to the laboratory for detailed examination of the associated flora and fauna. Mobile fauna, such as fish and larger crustaceans were recorded at the site during diving.

3) Re-colonisation of harvested areas

Spot and strip harvesting was applied to mimic the impact of scouidou and trawl harvesting, respectively. For spot harvesting, all kelp plants were removed in a circular area of 5 metres in diameter mimicking the impact of a scouidou. For strip harvesting an area of 2 by 10 metres was cleared, similar to the impact of a Norwegian dredge-trawl. Both methods were applied for *L. digitata* as well as for *L. hyperborea* in duplicate. After the clearing, re-colonisation of these areas by kelp species and associated flora and fauna was monitored every three months. The initial removal of kelp plants was conducted in March 2002.

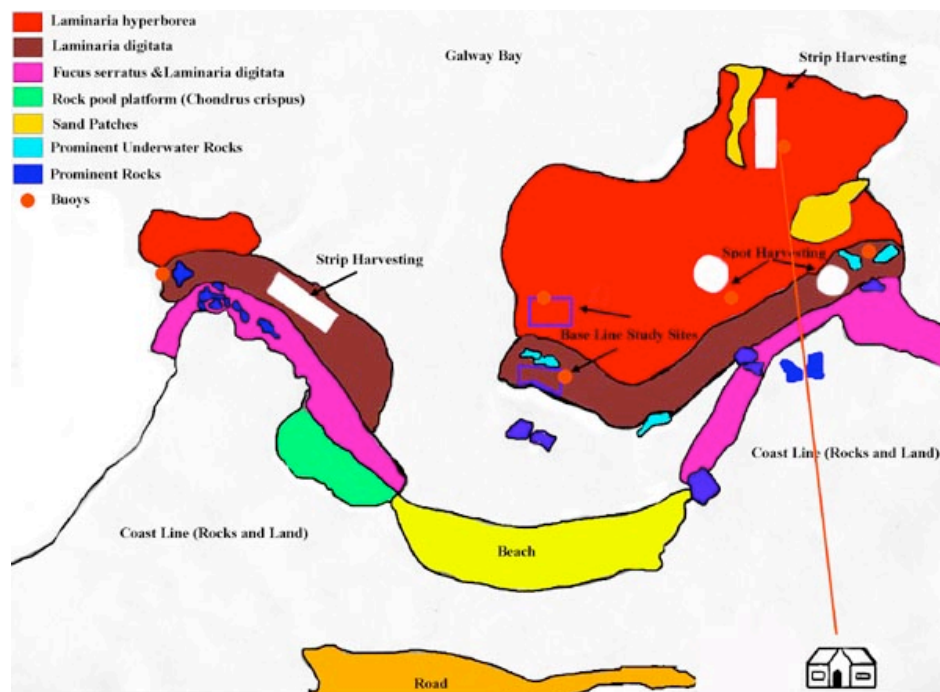


Fig. 5.1. Detailed map of the study area. Zones of dominant species are differentiated by colour, and harvesting sites are indicated (see legend).

5.2 Results

1) Determination of biomass and growth rates

Growth as well as biomass of *L. digitata* and *L. hyperborea* showed pronounced seasonality (see Fig 5.2). For both species, growth rates were highest in early spring. Thereafter, growth rates declined until they reached a minimum in late summer. In contrast to *L. digitata*, *L. hyperborea* ceased growth during autumn/winter and started with the development of a new blade in late winter/early spring. Growth rates of *L. digitata* varied between 0.08 and 0.16 cm per day and those of *L. hyperborea* between 0.0 and 0.17 cm per day, resulting in an average annual growth rate of 40 - 60 cm and 35 - 75 cm, respectively. Similar growth rates for *L. digitata* have been recorded by Pérez (1969) in Brittany/France and Lüning (1990) at the island of Helgoland/German Bight. Gomez & Lüning (2001) found even higher growth rates for *L. digitata* of ca. 90 cm per annum. For *L. hyperborea*, comparable growth rates of 70 cm in spring have been found in Norway (Sjoetun 1995; Sjoetun *et al.* 1998).

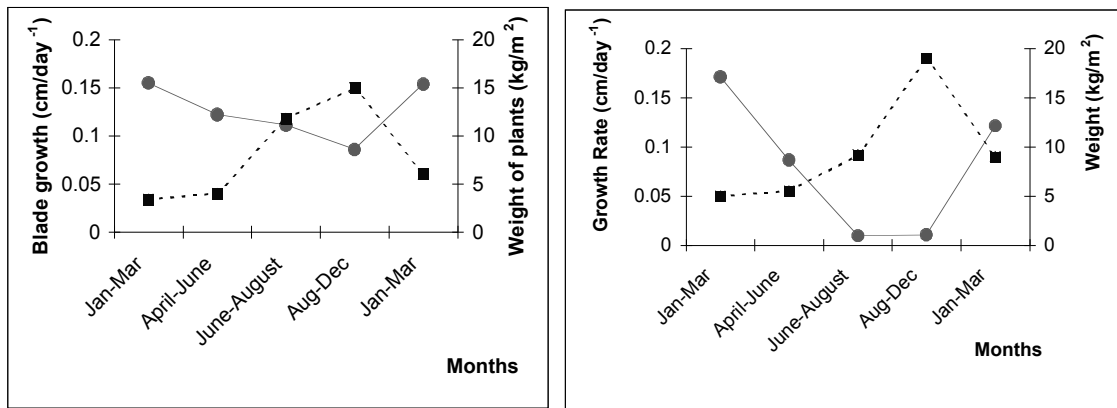


Fig. 5.2. Growth rates (solid line) and wet weight of plants per m² (broken line) of *Laminaria digitata* (a) and *L. hyperborea* (b), measured over a year's period at Spiddal, Co. Galway (S. Kraan & J. Morrissey, 2002, unpubl. data).

The wet weight of plants per m² of both *L. digitata* and *L. hyperborea* increased steadily from early spring and reached highest values in autumn. The decrease of biomass per m² during the winter months was mainly caused by loss of whole plants, but also by loss of old tissue at the distal end of the kelp blades. The biomass of *L. digitata* varied between 3.4 - 15 kg m⁻² and for *L. hyperborea* between 5.8 - 19.05 kg m⁻² in spring and autumn, respectively. In Brittany, biomass variations between 2 - 10.5 kg m⁻² were recorded for *L. digitata* (Arzel, 1998). In Norway, standing crop of *L. hyperborea* was reported to be 6 - 16 kg m⁻² at a depth of 3 - 5 metres (Sjoetun *et al.*, 1993) with maximum values of 27 - 41 kg m⁻² in some areas (Sivertsen, 1991).

2) Flora and fauna associated with kelp plants

During the course of the present study a total of 50 *L. digitata* and 50 *L. hyperborea* plants were examined. A total of 17 floral epiphytes and 55 species of fauna have been identified living on the stipe, blade and holdfast of *L. hyperborea*. This is consistent with the number of species recorded previously on kelp in Ireland and in Norway (Edwards, 1980; Christie *et al.*, 1998 and Evertsen, 2003). Lower numbers were found for *L. digitata* with 9 floral epiphytes and 14 species of fauna (see Appendix 1). Most species were encountered on the stipe and holdfast. The blade contained fewer species and often only a few dominant species. Generally, only on the oldest part of the blade of both *Laminaria* species epiphytic settlement is taking place, whereas no epiphytes are found on growing tissue.

3) Re-colonisation of harvested areas

Re-colonisation of a strip harvested area (2 x 10 m) within the *L. hyperborea* forest was monitored. All adult kelp plants were harvested in March 2002. A baseline for species associated with *L. hyperborea* is given in Appendix 1. With the removal of kelp plants all epiphytically growing organisms were also removed.

Three months after the clearing of the area (June), small plants of *S. polyschides* had developed and a substantial number of *Dilsea carnosa* plants were present compared to undisturbed areas. One of the most obvious changes was the disappearance of the edible sea urchin *Echinus esculentus*, but also other large mobile species, such as lobster, crabs and other sea urchins had left the harvested area, except for the starfish (*Marthasterias glacialis*). Six months after the initial harvest (October) the following percentage ground cover of algae were noted: 40% *S. polyschides*; 20% *D. carnosa*; 10% *Audouinella* spp., *Ahnfeltia plicata*, *Polyides rotundus* and *Plocamium cartilagineum*; 10% *Corallina officinalis* and *Osmundea pinnatifida*; 5% *Chondrus crispus*; 5% *Phyllophora crispa*, 1% *Ceramium nodulosum*, *Ceramium rubrum* and *Plumaria elegans*, and 4% crustose coralline algae. Specimens of *Lomentaria clavellosa*, *Acrosorium* spp., and *Dictyota dichitoma* were also found.

After one year, the first small plants of *Laminaria* species were found, which could not be identified to species level at this stage. Small plants of *S. polyschides* (20%) were also found. *Dilsea carnosa* (5%) was present but at lower levels than the year before. Species composition was similar to that of the previous year, although the proportions of coverage had changed. This might be a seasonal effect (e.g., *Delesseria* is a winter/spring species and is not present during the summer). There were no sea urchins present in the harvested area; however, numerous species of starfish were recorded, i.e. *Luidia ciliaris*, *Asterias rubens*, *M. glacialis* and *Asterina gibbosa*. One of the most remarkable events seen during the experiment was the appearance of *S. polyschides* during the summer, its disappearance in winter and re-appearance in spring. This was not observed within the neighbouring kelp forest.

During the SEASURF project, it was not possible to monitor re-colonisation for more than a year. Therefore, a full restoration of the harvested area was not observed, although regrowth followed a similar pattern recorded in other studies (Kain, 1976b and Sivertsen, 1991). The replacement of *S. polyschides* by *L. digitata* and/or *L. hyperborea* is reported to take two to three (Kain, 1976b, R. Kaas, IFREMER, 2003, pers. comm.).

5.3 Calculation of natural kelp resources

Based on the measurements of kelp biomass during a one-year period, the standing stock for Galway Bay from Carraroe to Black Head was calculated. The area in which kelp forests are established, was calculated as follows: The maximum depths of kelp forests were obtained by SCUBA diving and were marked on Admiralty Charts. The upper limits of kelp forests were extracted using aerial photography (Coastal CD-ROM series, Marine Institute) and also marked on the Admiralty charts. Total area of kelp forests was calculated using image analysis. By multiplying biomass figures (kg m^{-2}) with area, the total tonnage of kelp for Galway Bay was obtained. With this method, the biomass of kelps in total (*L. digitata* and *L. hyperborea*) was calculated.

The area of Galway Bay covered with kelp forest was estimated to be 10.7 km^2 . Minimum biomass was recorded with 3.4 kg m^{-2} for *Laminaria digitata* in spring and maximum biomass measured with 19.05 kg m^{-2} for *L. hyperborea* in autumn. Using an estimated average annual biomass of 7.63 kg m^{-2} of kelp, a total biomass of 81,641 tonnes of kelp (*L. digitata* and *L. hyperborea*) is calculated for the bay accordingly. Because of the large annual variations in biomass it is difficult to give accurate values for standing stock. Standard deviation and standard error of samples were 0.0055 and 0.0018, respectively. Using 95% confidence limits, the values for biomass are between 36,738 and 118,379 tonnes for Galway Bay.

The calculated biomass figures can also be used to get an estimation of natural kelp resources for the whole coastline of Ireland. The length of the Irish coast is stated to be 7,500 km at the low tide mark (Marine Institute, 1999). Due to the absence of suitable hard-bottom substratum and consequently well-developed kelp beds, the East coast (ca. 500 km) was excluded from the calculation. An additional 44% of the remaining coastline comprises sandy beaches and estuaries, which do not support kelp forest, and has to be subtracted accordingly (Hession *et al.*, 1998), leaving 3920 km of coastline, on which kelp forests are found. The average width of kelp beds was found to be about 100 m for Galway Bay. Using the estimated average annual biomass of 7.63 kg m^{-2} , a total biomass of about 3,000,000 tonnes of kelps is estimated to be present at the Irish coast (Table 5.1).

Table 5.1

Natural kelp resources in Ireland, France and Norway, and actual biomass utilised.

Country	Total natural kelp resources (tonnes)	Annual tonnage utilised		Total tonnage utilised
		<i>L. digitata</i>	<i>L. hyperborea</i>	
Ireland	3,000,000* (<i>L. dig</i> + <i>L. hyp</i>)	105	2,510	2,615
Brittany/ France	300,000 (<i>L. dig</i>) 5,000,000 (<i>L. hyp</i>)	60,000	2,500	62,500
Norway	15,000,000 (P) 10,000,000 (<i>L. hyp</i>)	100	180,000	180,100

Ireland: * = estimated biomass for *L. digitata* plus *L. hyperborea* (S. Kraan & J. Morrissey, 2003, unpubl.), other data from (Guiry, 1997); France: data from Kaas 1998 and Arzel, 2003, pers. comm.; Norway: P = Phaeophyta, data from (Jensen, 1998, Vea 2001, unpubl.).

In comparison to France and Ireland, Norway has the highest amount of natural resources of kelp, due to its long and rocky coastline. However, biomass figures for Norway and France show that standing stock of *L. hyperborea* exceeds by far that of *L. digitata*. *Laminaria digitata* beds are restricted to a certain zone on the shore with the upper distribution limit set by the low water mark and the lower limit set by the abundance of *L. hyperborea*. In contrast, *L. hyperborea* beds are limited in their expansion into deeper water only by light conditions (i.e. turbidity of coastal waters) and the availability of hard-bottom substratum. In Ireland, the majority of natural kelp resources are *L. hyperborea*. However, the standing stocks for each kelp species separately has yet to be established.

Notes on estimations of seaweed biomass

There is a range of methods available to estimate standing stock (i.e. spatial distribution and biomass) of seaweed. However, they differ significantly in resolution (discrimination between genera/species) and accuracy (best approximation of real standing stock of seaweeds). The different methods comprise space/air-borne and waterborn remote sensing as well as SCUBA diving. Space/air-borne methods, such as different types of satellite remote sensing and aerial photography are useful means for estimating spatial extension of aquatic vegetation in shallow coastal waters but they can also give biomass estimates (e.g. Hochberg & Atkinson, 2003; Simms & Dubois, 2001; Dahdouh-Guebas *et al.*, 1999 and Belsher & Mouchot, 1992). With these methods large areas can be surveyed in a relatively short time. Waterborn acoustic methods (e.g. RoxAnn, ecosounders) have been applied to survey, for example, seagrass beds and algal vegetation (Komatsu *et al.*, 2003 and Cole *et al.* 2001). Whereas seagrass and algal vegetation show specific characteristics and are therefore relatively unambiguously distinguished by a range of remote sensing methods (Dahdouh-Guebas *et al.*, 1999), the differentiation between *Laminaria* species is not possible because of their similar morphology and texture resulting in the reflection of an uniform signal (i.e. *L. digitata* and *L. hyperborea*, and their relative *S. polyschides*). Therefore, additional methods to "ground-truth" are required.

However, even sampling methods can result in significantly different biomass estimates. In the 1940s and 1950s extensive kelp surveys have been conducted along the Scottish coast to estimate *L. hyperborea* resources for the alginate industry (reviewed in Wilkinson, 1995). As an example, biomass estimates for *L. hyperborea* around the Orkney Islands from three different surveys were compared by Wilkinson (1995) and are shown in Table 5.2.

Table 5.2
Comparison of biomass estimates for *Laminaria hyperborea* around the Orkney Islands

Author	Method	Estimates of <i>L. hyperborea</i> standing stock for Orkney
V.J. Chapman (1948)	Extensive grab sampling with extrapolation to echo sounder readings	585,216 tonnes
F.T. Walker (1950)	Intensive grab sampling	1,219,200 tonnes
K. Walker (survey in 1980s; partially reported by Thompson 1983)	Echosounder with occasional estimates of ground truth by SCUBA diving	10,160,000 tonnes

Johnston (1985) suggested that the biomass figures for standing stock by F.T. Walker (1947, 1950) are an underestimate of natural kelp resources because small kelp plants would not be collected using the grab sampling method. Therefore these biomass figures should be considered as estimates of harvestable rather than total crop as small kelp plants would also be missed out by mechanical harvesting. In comparison, K. Walker's figures of standing crop are assumed as overestimates by Johnston (1985). He argued that sporadically verification of "ground truth" by SCUBA divers could lead to large errors when samples are collected only in dense kelp stands, which are not representative for the whole coastline.

This example shows that methods to estimate standing stocks of kelp resources have to be carefully chosen in order to get reliable figures on actual biomass of natural kelp resources.

5.4 Conclusions

Investigations into *L. digitata* and *L. hyperborea* and kelp ecology in Irish coastal waters are limited. Recent research conducted by the Irish Seaweed Centre provides initial information about kelp growth, biodiversity and regeneration of kelp forests after experimental harvesting. However, it must be noted that:

- a) The trials were conducted only over a one-year period, which is too short to monitor complete restoration of the kelp beds in experimentally harvested areas.
- b) These small-scale trials cannot substitute for investigations on the impact of commercially-used harvesting gear (e.g. scouidou and seaweed dredge).

Estimates of total kelp resources (i.e. *L. digitata* and *L. hyperborea*) for Galway Bay and extrapolation for the entire Irish coastline (areas with unsuitable substratum excluded) provides an approximation of kelp biomass. To make kelp resources accessible for exploitation, however, biomass estimates for *L. digitata* and *L. hyperborea* separately are necessary because the different biological characteristics of these two species mean they require different management strategies. The species also have different desirability in terms of exploitation.

5.5 Recommendations

In order to increase the knowledge of the kelp ecosystem and of specific characteristics of kelp species in Irish waters, further research programmes should be developed. The following would be seen as priority research areas:

- Resumption of the monitoring programme on the regeneration of kelp beds after the experimental harvesting similar to that carried out by the Irish Seaweed Centre as part of the SEASURF project. Experimental harvesting areas should be enlarged and trials should be carried out for a longer time period until restoration of the harvested areas is fully completed.
- Identification of areas where commercial mechanical kelp harvesting may take place and conduction of surveys on standing stock of *L. digitata* and *L. hyperborea*. Besides remote techniques, SCUBA diving should be applied to obtain more detailed information about biomass, density of standing stocks in relation to depth and exposure, extent of *L. digitata* and *L. hyperborea* beds, proportion of other kelp species in the kelp forests and the abundance of herbivorous grazers.
- Comparative investigations into growth rates of *L. digitata* and *L. hyperborea*, age class distribution and biomass in different parts of the Irish coast, which differ in exposure, water temperature and inorganic nutrient availability.
- Investigations into the reproduction times, recruitment and effective spore dispersal distance of the kelp species of interest.
- Interdisciplinary studies on kelp forest ecology in Irish coastal waters, which may comprise biodiversity, productivity of kelp forests and food webs. Additionally, some aspects (e.g. studies on fish using kelp forests as nursery grounds) may be of wider interest for, for example, the management of commercial fisheries.

LEGAL FRAMEWORK FOR SEAWEED HARVESTING IN IRELAND AND IMPLICATIONS OF SPECIAL AREAS OF CONSERVATION ON THE EXPLOITATION OF SEAWEEDS

6.1 Irish legislation for seaweed harvesting

The legislation for seaweed harvesting is based on the Foreshore Acts 1933 - 1998. It is stated that the foreshore is State owned. The foreshore comprises the seabed and shore below the line of high water at medium tide and extends outwards to the limit of twelve nautical miles. Under Section 3(1) the Minister for Communications, the Marine and Natural Resources (DCMNR) is empowered to grant licences for the removal of seaweeds, whether growing or rooted on the seabed (out to 12 miles), or deposited or washed upon the beach. The existing powers at the Ministers disposal for licensing harvesting of seaweed were found to be adequate by the National Seaweed Forum in 2000.

Under the existing legislation, there are no restrictions on quantities of seaweed that one is allowed to harvest. There are also no restrictions on harvesting times. The only exception concerns the exploitation of maërl, for which the maximum harvest of 10,000 tonnes per annum is given. Unattached coralline algae, referred to as maërl, show very low growth rates algae (0.6 - 1.5 mm per annum; De Grave *et al.*, 2000), which means that there is virtually no regeneration of maërl beds over decades. Additionally, maërl species are now listed under the EU habitats Directive 92/43/EEC for conservation and therefore exploitation is restricted (De Grave *et al.* 2000). The only other seaweed harvested in large quantities is *A. nodosum*. Due to high demands by the alginate industry, a maximum of 62,000 tonnes (wet) of *A. nodosum* was harvested in 1979 (Guiry & Hession, 1998). As a result of changes in the alginate market and changes in market focus of the main *Ascophyllum* processing company, the volume of harvest biomass decreased to 32,140 tonnes in 1994 and further to about 20,000 tonnes *per annum* in recent years (T. Barrett, Arramara Teo., 2003, pers. comm.). Annual quantities for other seaweeds, such as *Chondrus crispus* (carrageen moss), *Palmaria palmata* (dulse), *Fucus* spp. (wracks), and *L. digitata* are estimated to be between 50 and 250 tonnes. At present all seaweeds, apart from maërl, are hand-harvested.

6.2 Special Areas of Conservation

In recent years a substantial number of marine candidate Special Areas of Conservation (cSAC) have been designated in Ireland. The EU habitats Directive 92/43/EEC of 1992 obliged all member states to protect certain types of habitats, which were identified as being of European importance. The relevant legislation for implementing the habitats directive in Ireland is the European Communities (Natural Habitat) Regulations, 1997 (S.I. No. 94 of 1997). SACs are identified as outstanding examples of selected habitat types or areas important for the continued well-being or survival of selected species other than birds. The Government is obliged under EU law to protect these habitats. Table 6.1 gives an overview of marine habitat types, which are recognised under SAC legislation.

The selection of marine cSACs in accordance with EU law was based on a BioMar survey (1995). The resultant data were assessed by Dúchas (now National Parks and Wildlife Service (NPWS)) for biological interest and nature conservation and used as

a basis for designation of conservation areas (Kelly *et al.* 2001). The majority of marine cSACs were proposed in 2000.

Table 6.1

List of marine habitat types classified under existing SAC legislation.

Marine Habitat no.	Habitat Description
1.1	Open marine waters, inlets and bays, tidal rivers and estuarine channels, marine caves, reefs, submerged sandbanks
1.2	Mudflats and sandflats, sandy coastal beaches, shingle beaches, boulder beaches, bedrock shores, marine caves
1.3	Saltmarshes
1.4	Sand dunes and machair
1.5	Brackish lakes, lagoons
1.6	Rocky sea cliffs, clay sea cliffs, sea stacks and islets (stacks, holms and skerries)

Each SAC habitat type/number has an accompanying list of notifiable actions. "The cutting or harvesting of growing seaweed", for example, is a notifiable activity in habitat 1.1 and 1.2 and therefore requires consent from the Minister for Communication, Marine and Natural Resources. In the explanatory note in Dúchas's (NPWS) official SAC announcement (CITATION) it is stated that:

"In most cases the Minister's objective of sustainable use is met by a continuation of the current practices and after a consultation period, the user will continue as s/he always has".

"In some cases an intensification of exploitation will not be environmentally sustainable or a use will be environmentally damaging and it will not be acceptable to the Minister. In these cases the activity must be discontinued and a compensation system will be invoked."

So far, there have been no restrictions on seaweed harvesting, which is conducted in the traditional manner of hand-cutting. However, a substantial increase in biomass harvested would require the consent of the Minister for Communication, Marine and Natural Resources. The minister can issue the licence in the absence of approval from NPWS.

6.3 Conclusions

Existing legislation for seaweed harvesting, which is conducted in the traditional way of hand harvesting, was found to be adequate by the National Seaweed Forum (2000). A Foreshore licence typically allows the harvester to remove seaweeds without restriction on quantities and harvesting times. The harvesting areas are specified and requested for by the licence applicant, which may or may not be approved by the Minister. The introduction of mechanical harvesting would require a more comprehensive legislative framework to ensure sustainable seaweed harvesting for the following reasons:

- Larger quantities of seaweed would be expected to be harvested compared to the traditional harvesting of *A. nodosum* which, at present, is the only seaweed harvested in large quantities.
- In comparison to the intertidal species *A. nodosum*, the impact of harvesting on subtidal kelp species, regrowth and restoration of kelp beds must be monitored.
- Kelp species are habitat forming species and therefore important for the integrity of the complex kelp forest ecosystem.

6.4 Recommendations

The advent of mechanical harvesting of seaweeds in Ireland would necessitate a review of existing legislation to ensure sustainable and environmentally acceptable growth of the Irish seaweed industry. The experience gained and regulations applied in France and Norway should be taken into account. Any introduction of mechanical kelp harvesting and the development of associated management schemes should only be developed based on comprehensive environmental and economic assessments.

Any potential kelp harvesting areas should be outside protected areas. However, possibilities of limited kelp harvesting in cSACs may be discussed as a means to keep harvesting rates of kelp low in all potential harvesting areas as a precautionary approach to sustainable and sensible exploitation.

It is recommended that only standardised and proofed harvesting equipment should be used. Licence for installation of harvesting machinery on a boat might be considered and vessel safety regulations should be reviewed accordingly.

FACTORS AFFECTING THE DEVELOPMENT OF MANAGEMENT STRATEGIES FOR SUSTAINABLE MECHANICAL KELP HARVESTING IN IRELAND

Kelp forests represent complex and productive communities of temperate coasts worldwide (Mann, 1982 and Dayton, 1985). The high productivity and extended biomass of kelp and associated macroalgae support large numbers of invertebrates, fish and mammals, which utilise kelp as food resource and habitat (Dayton, 1985). Kelp forests also play a vital role for adjacent benthic communities in shallower and deeper water due to the high production of organic matter. Moreover, they show a high capacity for restoration after disturbance, either caused by naturally occurring events (e.g. heavy storms) or human impact (i.e. harvest). However, the time period required for regeneration varies with the stock forming kelp species, and may be affected by the abundance of other competitive seaweeds and/or the impact of grazers (Kain, 1976b; Sivertsen, 1997 and Arzel, 1998).

With the introduction of mechanical kelp harvesting, large amounts of biomass can be removed from kelp beds in a relatively short time, which can cause severe disturbance of the whole kelp-associated ecosystem. Therefore, comprehensive knowledge of the complex biological structures of kelp forests is essential to support sustainable harvesting practices and to develop suitable resource management plans. A comprehensive, precautionary approach, for example, was pursued in Eastern Canada in developing a management strategy for *A. nodosum* (Ugarte and Sharpe, 2001). Experiences from other countries are highly valuable with respect to ecobiological aspects, harvesting equipment, organisation of harvesting, resource management and legal aspects. However, direct knowledge transfer between regions/countries may not be possible due to differences in kelp growth, coastal and hydrothermal characteristics. In the following paragraphs, some aspects are highlighted, which are thought to be of importance in the process of developing management strategies for sustainable kelp harvesting in Ireland.

7.1 Considerations on eco-biological aspects

Sound scientific knowledge of kelp-forest ecology is essential for the development of the best harvesting practice to support sustainable exploitation of seaweed resources. In France and Norway, mechanical harvesting was and still is accompanied by extended research programmes, conducted by the industry and independent research institutions. These are essential to adjust harvesting practices if sustainable harvesting is not being achieved. This was, for example, shown in Norway, where scientific investigations led to the extension of fallow periods from 4 to 5 years (see Chapter 4.3). Comprehensive long-term research programmes, perhaps similar to those in Norway, should be considered for Ireland to collect information on specific characteristics of kelp and to assess the impact of mechanical harvesting. Initial small-scale studies on the impact of kelp harvesting have been conducted recently by S. Kraan & J. Morrissey (2003, unpubl. data, see Chapter 5). Although conducted over only a short period, the investigations provide valuable information in, for example, confirming similarities to growth rates, biodiversity and succession pattern after harvesting that were found elsewhere. They also identified factors that may have an adverse effect on regeneration of kelp. These factors are the abundance of *S. polyschides* and the occurrence of grazers, both of which have a severe effect on kelp beds in France and Norway, respectively.

Saccorhiza polyschides

This kelp is a native species to Ireland. Normally, it grows in patches, which are not colonised by *L. digitata* and *L. hyperborea*. As an opportunistic species, however, it is capable of colonising cleared areas within *Laminaria* stands and suppressing regrowth of *L. digitata* and *L. hyperborea*, as shown in the study by S. Kraan & J. Morrissey (2003, unpubl. data). After two to three years, *S. polyschides* is outcompeted by the perennial *Laminaria* species, as several studies have shown (Kain, 1976b and Arzel, 1998). Therefore, if kelp beds are harvested, it is essential to apply a fallow period of at least two years (for *L. digitata*) to allow full replacement of *S. polyschides* by commercially important kelps. The distribution of *S. polyschides* might be advanced by a minimal increase in coastal water temperature, as suggested for France. *Saccorhiza polyschides* is found in moderate abundance in Galway Bay (S. Kraan & J. Morrissey, 2003, unpubl. data) but is apparently highly abundant in the south-east of Ireland as concluded from the large quantities of biomass found washed upon several beaches near Kilmore Quay (S. Kraan & A. Werner, August 2003, unpubl. data). However, it is not clear whether *Saccorhiza polyschides* is mainly growing in areas, which are not suitable for kelps, or whether it has replaced kelp species. It is recommended that the abundance of *S. polyschides* at potential kelp-harvesting sites along the coast is surveyed prior to initiation of mechanical harvesting.

Kelp grazers

In several areas in Mid and Northern Norway, destructive grazing by the green sea urchin *Strongylocentrotus droebachiensis* led to the creation of barren grounds, which can persist over several years (Sivertsen, 1997). Fortunately, this species does not occur in Ireland (www.marlin.co.uk/species/strongylocentrotusdroebachiensis.htm). Other sea urchins, such as the indigenous edible sea urchin *E. esculentus*, are found to be capable of heavy grazing and may have an impact on kelp regrowth (Sjoetun *et al.*, 2000; Anonymous, 2002). Abundance of *E. esculentus* should be monitored when harvesting is conducted, although this species does not pose a severe threat to kelp beds compared to the green sea urchin. Another grazer, found in high abundances on kelp, is the blue-rayed limpet (*Helcion pellucidum*) (S. Kraan & J. Morrissey, 2003, unpubl. data). This species shows a migration pattern from crustose coralline algae at the lower shore to fleshy algae, such as *Mastocarpus stellatus* and *Laminaria* species. Apparently, *Laminaria* species are preferred for grazing by *Helcion*, as growth rates were found to be highest on kelp (McGrath, 1992). As stated by Kraan & Morrissey (2003, unpubl. data), heavy grazing of *H. pellucidum* on blade, stipe and holdfast of kelps may weaken the plants and consequently make them more susceptible to removal by wave action. Grazing pressure, however, was found to be higher in semi-exposed areas than in exposed sites (Sivertsen 1997; Sjoetun *et al.* 2000). This might be taken into account when selecting areas for harvesting.

7.2 Harvesting equipment

France and Norway have developed specialised harvesting equipment that is optimised for the harvest of the species of interest and for the prevailing coastal conditions. In France, the scoubidou is used to harvest *L. digitata*. In Norway, a seaweed dredge is used for the exploitation of *L. hyperborea*. Both harvesting equipment and fishing boats differ in effectiveness and carrying capacity, respectively. With the scoubidou, spots of *L. digitata* are harvested in areas, which are characterised by fissured rocky substratum dispersed with large numbers of boulders. Consequently, the equipment-defined way of harvesting small patches is probably the best method for exploitation. The rotating hook of scubidou can only harvest the spot

where it is dipped into the water. In these rocky areas it is not possible to drag a dredge over the bottom. In addition, small boats are advantageous to operate in these shallow, rugged areas. The dredge-trawl method, by which long stripes of *L. hyperborea* are harvested, is adjusted to rocky bottoms with fewer interruptions by rocks and boulders. The boats have to be stronger and bigger to operate further off the coast in exposed sites.

In 2000, harvesting trials on *L. digitata* using the French equipment were conducted in Bantry Bay, Co. Cork, by the company Seaweed South-West with the assistance of BIM (Irish Sea Fisheries Board). Apparently, *L. digitata* was not removed as efficiently by the scoubidou as in France. It was stated that *L. digitata* plants in Ireland have a shorter, more rigid stipe, which impaired the effectiveness of removal by the scoubidou (M. Sammon, 2003, pers. comm.). This may lead to a higher percentage of blades being removed, leaving the stipe behind, which then would deteriorate. Reduced efficiency in the removal of entire plants and losses of plants when the harvesting equipment is pulled up can result in an increase in detritus in the harvest area, which may attract grazers and influence the turnover of organic matter. It also may lead to an underestimation of removed biomass in relation to standing stock, because it may not consider the percentage of wastage or damaged plants that will subsequently die off. Efficiency of harvesting equipment should therefore be investigated in detail, not only for economical reasons but also with respect to the integrity of the ecosystem.

Beside the French scoubidou and the Norwegian seaweed dredge there is no other mechanical method specifically developed for harvesting of *Laminaria* species. Modification of the type of machinery used for harvesting *A. nodosum* in Norway, a so-called suction cutter (Jensen, 1998) might also be possible and as an alternative for harvesting kelp in Ireland.

7.3 Resource management

For sustainable resource management a range of aspects has to be considered:

- Biology of kelp beds (i.e. growth, reproduction, regeneration, restoration of kelp associated flora and fauna)
- Standing stock
- Fallow periods
- Species and their quantities demanded for utilisation by the industry
- Control mechanisms to monitor biomass harvested
- Control mechanisms to secure sustainability of natural resources
- Potential conflicts with other users of the resource e.g. fishermen

Aspects of the biology of kelp forests have already been discussed. The knowledge of standing stocks and the location of kelp beds suitable for harvesting are a prerequisite for developing a management strategy. Estimates of total biomass of kelp in Ireland have been given recently by S. Kraan & J. Morrissey (2003, unpubl. data). However, it would be essential to have detailed figures of the standing stock of both *L. digitata* and *L. hyperborea*. These species differ in various biological aspects (e.g. growth, longevity, habitat forming aspects). They also differ in stock-forming biomass. Therefore, resources of each species should be managed differently, especially with respect to the application of fallow periods. In Norway, the harvesting cycle for *L. hyperborea* is 6 years (Vea 2001, unpubl.). In France, there is no official regulation on fallow periods, but due to the recent decline of *L. digitata* beds scientists

recommend a fallow period of at least two years for this species (P. Arzel & R. Kaas, IFREMER, 2003, pers. comm.). For Ireland, S. Kraan & J. Morrissey (2003, unpublished data) recommended fallow periods for *L. hyperborea* and *L. digitata* of 5 - 6 and 2 years, respectively, based on growth rates (see Table 7.1).

Table 7.1
Growth and regeneration time of *Laminaria* species

Species	Average length	Average growth per annum	Regeneration Time
<i>L. hyperborea</i>	1.33 m	0.26 m	5.12 years
<i>L. digitata</i>	0.7 m	0.43 m	1.6 years
Kelp(both species)	1.01 m	0.35 m	3.14 years

(from S. Kraan & J. Morrissey, 2003, unpubl. data)

Another aspect requiring regulation is the percentage of standing stock allowed to be harvested. In Norway, 15 - 20% of the standing stock of *L. hyperborea* is harvested annually, whereas in France about 30% of total biomass of *L. digitata* is removed (Vea 2001, unpubl.; P. Arzel, 2003, pers. comm.). In addition, a certain percentage of biomass is removed naturally every year due to storms, grazers and age of plants (estimated to be 10 - 20% in Norway and up to 50% in France). This brings the total biomass removed from standing stock close to or even over 50% and may lead to over-exploitation. The effects of harvesting a high percentage of standing stock are certainly more severe for a slow-growing, long-lived species like *L. hyperborea* and the associated flora and fauna than for a faster growing species like *L. digitata*. As a precautionary measure it would be advisable to allow not more than 10 - 15% of total biomass to be harvested per annum. If quotas are introduced, detailed figures of the standing stock are essential, as well as measures to control the compliance with quotas.

Control mechanisms are vital for effective resource management. Methods of controlling the landings of seaweeds would, for example, be required. In Norway and France, kelp is almost exclusively harvested for the alginate industry, i.e. for one purpose, and therefore relatively easy to control. In Ireland, the situation may be different with several independent harvesters supplying a number of different markets; and there may be a demand for both *L. digitata* and *L. hyperborea*. Another important aspect requiring consideration is the regulation of licenses. Existing legalisation may not be adequate for inclusion of mechanised harvesting of seaweeds.

Additional control mechanisms to ensure sustainable harvesting and continued integrity of the ecosystem also have to be considered. Monitoring of harvested areas combined with research programmes would be a means of managing the resource sustainably. Responsibility for monitoring programmes should be taken over by the industry as well as by independent institutions.

Laminaria species are used in a broad range of products. They are used for the production of agrochemicals and fodder, in biotechnology, for biomedical applications and by the cosmetic industry. The largest quantities of *Laminaria* species, however, are utilised by the alginate industry. If Irish kelp resources are made accessible to mechanical harvesting, it will be difficult to predict the demands that may arise from industry with regard to quantities and species, without appropriate background research. Therefore, an assessment of existing demands, prices for raw material, and potential purchasers would be useful.

7.4 Conclusions

In order to develop a management strategy for sustainable mechanical kelp harvesting, a range of different aspects has to be considered. The management of kelp resources requires more complex regulations than that of the current bulk species *A. nodosum* and others that are harvested in small quantities. The important issues relating to the introduction of mechanical kelp harvesting fall into four categories:

- 1) *Biological issues*, such as the biology of kelp species, the ecology of kelp forests and their interaction with benthic intertidal, subtidal and pelagic communities, research and monitoring programmes and estimates of kelp resources.
- 2) *Technical issues*, comprising harvesting equipment and logistical aspects, such as landing ports and means to control landings of raw material.
- 3) *Information about the economic viability of kelp harvesting*, such as demand of raw material in near future, potential applications and markets, potential opportunities for expansion of the Irish seaweed industry as a result of facilitating access to domestic natural kelp resources.
- 4) *Resource management*, comprising regulations on area allocation, fallow periods, harvesting times, biomass quotas, and the control mechanisms for the compliance with official regulation and the sustainable use of natural resources. This should also include the licensing measures to support these issues.

The experience gained to date of seaweed harvesting in Ireland, as well as specific experiences on kelp harvesting in other countries provide a valuable source of information. Kelp resource management is well established in France and Norway and may serve as model for the development of a management strategy for Irish kelp resources, after adjustment to Irish conditions and requirements. In order to define precisely the requirements however, more information, especially with respect to biological issues, is needed.

7.5 Recommendations

A management strategy is essential for the development of a sustainable kelp harvesting industry in Ireland. In the process of developing such management strategy, the following steps and measures are recommended:

Research and surveys

- Research programmes to investigate aspects of kelp biology and ecology should be initiated. Surveys should be conducted to assess natural resources for *L. digitata* and *L. hyperborea* separately. It is recommended that the reproduction times of kelp populations in different areas, which might be of interest to harvesting, are investigated. Subsequently, harvesting times should be determined avoiding kelp cutting at peak times of reproduction.
- The volume of natural annual losses of kelp plants should be investigated. This information is essential when establishing the percentage of harvestable biomass.

Harvesting trials

- Harvesting trials should be carried out. As an essential part of the trials, the environmental impact of mechanical harvesting should be monitored. Accompanying research programmes should be designed as long-term studies. Harvesting equipment should be assessed for its suitability and efficiency in Irish coastal waters (see Chapter 7.2). It is essential that, in the process of harvesting that young kelp plants are left in order to form the crop of the years to follow. The development of new purpose-built harvesting equipment may be considered.

- Harvesting trials should be carried out at different times of the year to investigate the seasonal influence on the regeneration of kelp beds.

Evaluation of the economical viability of kelp harvesting

- Information on the possible demand of raw materials by the industry, as well as expected demand in the future would be advantageous in the process of planning, especially with respect to the allocation of harvesting areas and potential landing ports. This would also be crucial for the development of a sound management strategy. In contrast to Norway and France, where only one species is utilised mainly for domestic use, by one or two companies, it is assumed that in Ireland both *L. digitata* and *L. hyperborea*, will be harvested for, or by, a number of companies for domestic use or export. Therefore, different management measures for controlling the natural resources would be expected to be put in place. Additional data should therefore be collected by the relevant agencies, in collaboration with the industry.
- The evaluation of potential markets (domestic and international) should form part of an assessment of the economic viability of kelp harvesting.

Evaluation of suitable kelp harvesting sites

- Detailed surveys should be conducted to estimate the extent of our natural resources and the density of standing stocks of *L. digitata* and *L. hyperborea*. Based on these estimates, areas can be allocated and subdivided into smaller units to allow rotation of fields to comply with fallow periods.
- Besides the biomass and density of kelp plants, additional selection criteria for suitable sites should include information on the presence of the opportunistic alga *S. polyschides* and grazers (i.e. sea urchins and the blue-rayed limpet)
- It should be clarified if and under which conditions kelp harvesting could be allowed in marine cSACs.
- Potential interference of kelp harvesting activity with other coastal resource users should be evaluated.

Management strategy

- A management strategy for Irish kelp resources should be based on precautionary measures so as to ensure the sustainable harvesting and long-term integrity of the ecosystem. Resource management programmes established in France and Norway are thought to be valuable examples to assist in the development of a management plan for Irish kelp resources.
- Different management schemes of kelp beds would be necessary for *L. digitata* and *L. hyperborea* with respect to, for example, fallow periods.
- The percentage of biomass removed from a kelp bed should be low. For *L. digitata* it should be lower than that applied in France.
- The existing legislation for seaweed harvesting may need to be re-examined and adjusted for mechanical harvesting.
- Frequent monitoring programmes to assess the environmental impact of mechanical kelp harvesting should be established as part of the management scheme. Responsibilities for conducting these programmes should be taken over by the industry as well as independent institutions.
- Measures to control the volume of biomass removed from an area should be developed (e.g. allocation of landing ports with installations to weight landings, compilation of records of landings, evaluation of these data on an annual basis).

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Appendix 1

List of species associated with *Laminaria* species

In the following table species are listed, which were found associated with *Laminaria hyperborea* and *L. digitata* at different times of the year when kelp species were harvested for biomass measurements.

Species encountered on <i>Laminaria hyperborea</i>	01/03/2002	01/05/2002	01/09/2002	01/12/2002
Flora				
Chlorophyceae				
<i>Cladophora rupestris</i>			1	
Rhodophyceae				
<i>Phycodrys rubens</i>		x	x	x
<i>Pterosiphonia pennata</i>		1	2	1
<i>Lithophyllum</i> spp.		x		x
<i>Lithothamnion</i> spp.		x	x	x
<i>Phyllophora crispa</i>		20		
<i>Polysiphonia</i> spp.		1		
<i>Polysiphonia lanosa</i>			1	
<i>Corallina officinalis</i>	x			x
<i>Palmaria palmata</i>	x		x	x
<i>Lomentaria articulata</i>	x		7	
<i>Ptilota gunneri</i>	x		x	
<i>Delesseria sanguinea</i>			2	x
<i>Cryptopleura ramosa</i>			x	
<i>Membranoptera alata</i>			x	
Phaeophyceae				
<i>Laminaria digitata</i>			1	x
<i>Saccorhiza polyschides</i>				2
Fauna				
Porifera				
<i>Scypha compressa</i>	5	5		2
<i>Pachymatisma johnstonia</i>		1		1
<i>Myxilla</i> spp.		1		1
<i>Hemimyscale columella</i>	2			
Cnidaria				
<i>Dynamena pumila</i>	x			
<i>Anemonia viridis</i>			1	
Annelida				
<i>Nereis pelagica</i>		2		
<i>Pomatoceros lamarcki</i>		3		
<i>Spirorbis spirorbis</i>	x	x	x	
<i>Sabellaria alveolata</i>			3	
<i>Pomatoceros lamarcki</i>			2	

<i>Filograna implexa</i>			2	
<i>Megalomma vesiculosum</i>			2	
Crustacea				
Copepods	x	x	x	x
<i>Leptomycis</i> spp.: large school			1	
Juvenile crab		1		
<i>Calliopius laeviusculus</i>		1		
<i>Semibalanus balanoides</i>		x	x	
<i>Balanus crenatus</i>	5			3
<i>Gammarus</i> spp.			2	
<i>Pinnotheres pisum</i>			2	
<i>Verruca stroemia</i>	1			
Mollusca				
<i>Aplysia punctata</i>		1	1	
<i>Patella</i> spp.		1	x	
<i>Mytilus edulis</i>				
<i>Gibbula cineraria</i>		x	3	x
<i>Helcion pellucidum</i>	5	7	3	xx
<i>Acanthochitona crinitus</i>			1	
<i>Calliostoma zizyphinum</i>				5
<i>Retusa truncatula</i>	1			
Clam sprat	x	x	x	
Bryozoa				
<i>Conopeum reticulum</i>			x	x
<i>Scruparia chelata</i>			x	x
<i>Alcyonidium</i> spp.			x	x
<i>Callopora lineata</i>			x	x
<i>Electra pilosa</i>		x	x	x
<i>Celleporella hyalina</i>		x		x
<i>Cellaria</i> spp.		2		
<i>Membranipora membranacea</i>	x	x	x	x
Echinodermata				
<i>Marthasterias glacialis</i>			1	
<i>Asterias rubens</i>			1	x
<i>Asterina gibbosa</i>			5	x
<i>Ophiotrix fragilis</i>			1	
<i>Echinus esculentus</i>			2	2
Tunicata				
<i>Asciidiella aspersa</i>		1		
<i>Dendrodoa grossularia</i>		1	3	
<i>Didemnum coriaceum</i>		1		1
<i>Botryllus schlosseri</i>		1	1	1
<i>Aplidium</i> spp.		1		
<i>Molgula</i> spp.		1		
<i>Distomus variolosus</i>	7	3	2	
<i>Corella parallelogramma</i>		3		

<i>Morchellium argus</i>			2	
<i>Distomus variolosus</i>				
Chordata				
<i>Gobiusculus flavescens</i>			x	1
Species encountered on				
<i>Laminaria digitata</i>	01/03/2002	01/05/2002	01/09/2002	01/12/2002
Flora				
Rhodophyceae				
<i>Palmaria palmata</i>	x			
<i>Polysiphonia macrocarpa</i>				x
<i>Plocamium cartilagineum</i>		x		x
<i>Ptilota gunneri</i>	x	x	x	x
<i>Brongniartella bysoides</i>		x	x	
Crustose coralline algae	x	x	x	x
Phaeophyceae				
<i>Fucus</i> spp.		x		
Fauna				
Cnidaria				
<i>Dynamena pumila</i>	xx		x	
<i>Gonothyraea loveni</i>	x		x	
<i>Litosiphon</i> spp.		x		
Annelida				
<i>Spirorbis spirorbis</i>		x		x
<i>Pomatoceros triqueter</i>	x			
Crustacea				
<i>Balanus balanus</i>	x	x	x	
Mollusca				
<i>Helcion pellucidum</i>	x	x		x
<i>Littorina obtusata</i>			x	
<i>Littorina littorea</i>			x	
<i>Mytilus edulis</i>		x	x	
<i>Anomia ephippium</i>			x	x
<i>Heteranomia squamula</i>		x		
Bryozoa				
<i>Membranipora membranacea</i>	x	x	x	x
Tunicata				
<i>Ascidella aspersa</i>	x	x		x
<i>Distomus variolosus</i>		x		
Egg capsules				x